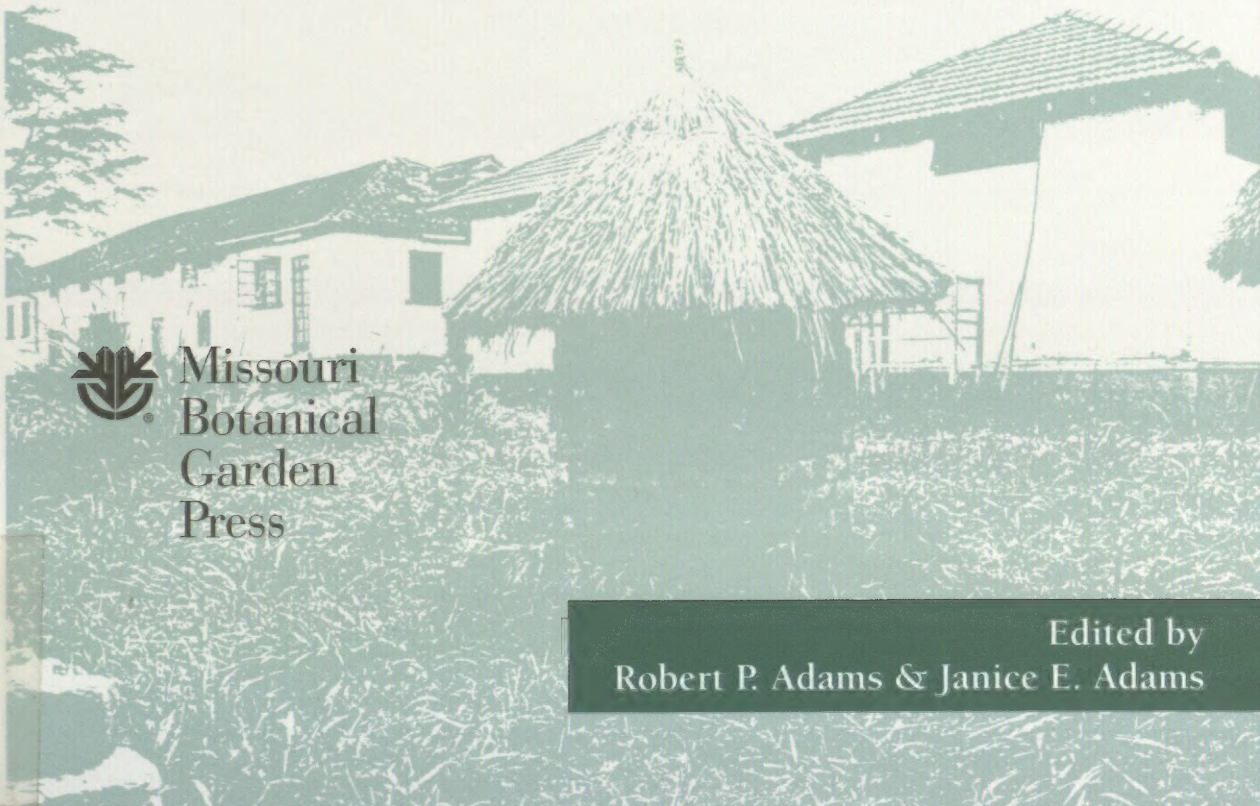
Conservation of Plant Genes III:

Conservation and Utilization of African Plants



Missouri Botanical Garden Press

Edited by
Robert P. Adams & Janice E. Adams

Conservation of Plant Genes III:

Conservation and Utilization of African Plants

REF
QK1
.M833
1998
v.71
c.3

Conservation of Plant Genes III:

Conservation and Utilization of African Plants

Missouri Botanical Garden Press

Edited by
Robert P. Adams & Janice E. Adams

MONOGRAPHS IN SYSTEMATIC BOTANY
FROM THE MISSOURI BOTANICAL GARDEN

Volume 71

ISBN 0915279568
ISSN 0161-1542

AUTHORS' ADDRESS

Plant Biotechnology Center
Baylor University
P.O. Box 669
Gruver, Texas 79040, U.S.A.

EDITOR
Victoria C. Hollowell

MANAGING EDITOR
Amy Scheuler McPherson

EDITORIAL ASSISTANT
Diana Gunter

TEXT FORMATTER
Barbara Mack

SECRETARY
Vicki Couture

COPY EDITOR FOR THIS VOLUME
Ann Thering

Copyright © 1998 by Missouri Botanical Garden Press.
P.O. Box 299
St. Louis, Missouri 63166-0299, U.S.A.
All rights reserved.
Printed in U.S.A.

The cover photo is a seed storage granary made of brick using sand and cassava as a substitute for cement in Uganda. Photo courtesy of Remigius Bukenya-Ziraba.

CONTENTS

Preface vii

DNA Bank-Net: A Perspective
Robert P. Adams 1

Plant Conservation in Africa: Political and Economic Realities
W. A. Rogers 9

Conserving Plant Genetic Diversity for Sustainable Food Production in sub-Saharan Africa
N. Q. Ng 25

The Conservation and Utilization of Plant Resources in East Africa: Issues in Forest Ecosystem Management
James Legilisho-Kiyiapi 41

Sustainable Use and Conservation of Arid and Semi-Arid Land (ASAL) Tree Species in Kenya: The Case of *Melia volkensii*
Titus K. Mukiama, Richard W. Mwangi and H. Rembold 51

Conservation of Plant Genetic Resources in Kenya
M. Isahakia, E. Obunga, Y. Morimoto, B. Kamondo and R. Aman 59

Conservation of Agro-Biodiversity in Tanzania
W. Y. F. Marandu and M. J. Nkya 69

Protected Areas and Plant Conservation in Tanzania: An Appraisal
William R. Mziray 77

Germplasm Collection and Conservation in Uganda: Prospects and Constraints
Remigius Bukenya-Ziraba 91

The Status of Plant Germplasm Conservation in Cameroon
Peter A. F. Foncho 107

Sustainable Conservation by the Cameroon Action Program
Amougou Akoa 119

Cassava Germplasm Collection and Conservation in Cameroon
Tumanteh J. Ambe and E. T. Awah 131

The Conservation Status of Zambian Vegetation
M. G. Bingham 137

The Conservation of Germplasm of Agricultural Plants in South Africa with Particular Reference to Vegetables, Potatoes, and Cassava
Joe J. B. van Zijl and Rihana Botha 147

Biodiversity of Phytogenetic Resources in Madagascar: Inventory, Utilization and Conservation for Durable Development
Rakotovao Ramasiarivelo Zoeliarisoa 155

Collection, Conservation, and Utilization of Medicinal Plants
Zac O. Gbile 163

The Missouri Botanical Garden's DNA Bank
James S. Miller and Heidi H. Schmidt 175

Survey of Laboratories Engaged in Molecular Biodiversity Analysis of Plants and Animals in Sub-Saharan Africa
L. Guarino and I. Dawson 183

Research and Training Needs in Conservation Approaches in Africa
A. A. Oteng-Yeboah 199

Conservation of Medicinal Plants: Selecting Medicinal Plants for Research and Gene Banking
J. N. Eloff 209

Safe Movement of Germplasm Between Countries
Roshan Abdallah and Robert Black 223

Obtaining Reproducible Patterns for RAPD DNA Fingerprinting as an Aid for Germplasm Evaluation
Robert P. Adams, Lori E. Flournoy and R. N. Pandey 229

Appendix I. List of Participants at the DNA Bank-Net III meeting in Nairobi, Kenya, 20–23 July, 1997, and their current interests 237

PREFACE

The third meeting of DNA Bank-Net was held in Nairobi, Kenya, on July 20–23, 1997. This was made possible by the support of the Wallace Genetic Foundation, who we thank for their foresight and continued interest in gene conservation. Although civil unrest in Kenya deterred some participants from attending, the spirit of the meeting was very positive. There was a tremendous concern about the changes in the status of plant species in Africa among the African scientists. As you read the stories of the attempts to stem the tide of species losses, you will, no doubt, be enlightened as to the problems facing every nation in Africa as they seek to balance the needs of expanding populations versus the desire to conserve their rich biodiversity.

Although the report from each country is a little different, you will find a common theme runs through all the reports: How can scientists make a difference in the political game of conservation? This point is very clearly elaborated in the W. A. Rogers paper. One should also examine the example appended to the paper by M. G. Bingham to see how the political system works in Zambia as well as most nations. Several papers point to particular problems of conservation in Kenya (Legilisho-Kiyiapi, Mukiama et al., Isahakia et al.). The status of conservation in Tanzania is addressed by Marandu and Nkya, and Mziray. Bukenya-Ziraba discusses the prospects and constraints for conservation in Uganda.

Three perspectives are given on the status of plant conservation in Cameroon (Foncho, Akoa, and Ambe and Awah). Mike Bingham gives a very good overview of the status of the Zambian vegetation as well as the appended case study. South Africa is clearly the leader in biotechnology in sub-Saharan Africa and the conservation of their agricultural germplasm is well conceived (Zijl and Botha). The vegetation in Madagascar is likely as threatened as any place on earth. Zoeliarisoa paints a vivid picture of the rate of forest losses and offers little prospect that *in situ* preservation will be effective in Madagascar. Medicinal plants have and continue to play an important role in Africa. Both Gbile and Eloff discuss the need for the preservation of medicinal plant germplasm, although from different perspectives.

Although only one DNA bank is represented in this book, it is fitting that Jim Miller presents information on the operation of the Missouri Botanical Garden, as this institute has both a strong collaboration with Africa and a keen role in plant conservation. Research and training needs are great in Africa, and Oteng-Yeboah gives a thoughtful discussion of the needs and constraints. Guarino and Dawson bring together very important information on the status of African institutions engaged in molecular biodiversity analysis. It is hoped that this information will lead to increased cooperation.

There is also an awakening of the threat of introduced, problem organisms and their impact on the native plants. Abdallah and Black discuss the safe movement of germplasm between countries.

The use of Random Amplified Polymorphic DNAs (RAPDs) in biology has exploded during the past several years. RAPDs are finding increasing utilization in germplasm evaluation. Adams et al. present some new information on the stability of RAPDs and give some very practical advice on helping to obtain reproducible results.

It is anticipated that, through these proceedings, the field of germplasm conservation in Africa will be enhanced.

Robert P. Adams, Dir. DNA Bank-Net
Baylor University

DNA BANK-NET: A PERSPECTIVE

Robert P. Adams
Plant Biotechnology Center, Baylor University, Box 669
Gruver, Texas 79040, USA rpadams@juno.com

SUMMARY

An overview of DNA Bank-Net is presented, including the rationale for the initiation and development. DNA Bank-Net will initially function as a reserve of DNA from rare and endangered tropical species and thus a genetic insurance policy against the loss of genes from the world gene pool. Now several DNA banks are dispensing DNA for various taxonomic uses. In the future, DNA Bank-Net will begin dispensing genes via PCR (Polymerase Chain Reaction) using primers supplied by users.

INTRODUCTION

There are many reasons that one should preserve the world's germplasm (or genetic resources). But the advent of genetic engineering has ushered in a new era in which genes are now available in a "horizontal" gene pool. This is because one can now move genes between quite unrelated plant (and animal) species. The value and instability of the world's genetic resources can be illustrated by two recent examples.

Vigna unguiculata (L.) Walp., discovered in a market in Ilorin, Nigeria, contains a protein that inhibits trypsin digestion by insects (Redden et al., 1984). This gene has been moved to tobacco (*Nicotiana*) where the trypsin-inhibiting gene is expressed and offers tobacco the same resistance against insects as in cowpea (Newmark, 1987). It is interesting to note that although a very active form of the gene has been found in a Nigerian cowpea, scarcely 100 of the world's 13,000 legume species have been examined for this gene. Yet, the tropical legumes, one of the most promising groups for the evolution of natural insecticides, will certainly be subject to considerable germplasm loss in the next decade.

Cultivated crops are extremely inbred for factors such as yield, uniform flowering and height, and cosmetic features of the products. This narrow genetic base has resulted in several disastrous crop failures. Ireland's potato (*Solanum tuberosum* L.) famine of 1846, which resulted in famine and the emigration of a quarter of its population, was due to the fact (Plucknett et al., 1987) that their potatoes had no resistance to the late blight fungus (*Phytophthora infestans*). This can be traced to the lack of genetic diversity in Irish potatoes, which had been multiplied using clonal materials from just two separate South American introductions to Spain in 1570 and to England in 1590 (Hawkes, 1979).

The recent example is the southern corn leaf blight (*Helminthosporium maydis*) in 1970 in the United States. Because almost all of the corn (*Zea mays* L.) in the United States was of hybrid origin and contained the Texas cytoplasmic male sterile line, our fields of corn presented an unlimited extremely narrow gene base habitat for the fungus. By the late summer of 1970, plant breeders were scouring corn germplasm collections in Argentina, Hungary, Yugoslavia, and the United States for resistant sources (Plucknett et al., 1987). Nurseries and seed fields were used in Hawaii, Florida, the Caribbean, and Central and South America to incorporate the resistance into hybrid corn

in time for planting in the spring of 1971 (Ullstrup, 1972). Without these genetic resources this technological feat would not have been possible.

The base collections of plant specimens have been utilized for the formulation of our understanding of morphological variation among taxa. Indeed, without the great herbaria of the world, our knowledge of plant evolution would be fragmented at the least. As we have moved into the era of utilizing chemical data for systematic and evolutionary studies, methods of preserving plant materials for future (chemical) work have been largely ignored. We are usually content to file a voucher specimen to document our chemical studies. With the present level of support for plant collections, it is unlikely that many of the world's plant species can be preserved by freezing so that scientists might have access to the study of secondary compounds, enzymes, or DNA/RNA in the coming centuries.

FORMATION OF DNA BANK-NET

Concurrent with advancements in gene cloning and transfer has been the development of technology for the removal and analyses of DNA. DNAs from the nucleus, mitochondrion, and chloroplast are now routinely extracted and immobilized onto nitro-cellulose sheets where the DNA can be probed with numerous cloned genes. Recent advances in the technology for the extraction and immobilization of DNA, coupled with the prospect of the loss of significant plant genetic resources throughout the world, has led to the establishment of DNA Bank-Net, an international network of DNA repositories for the storage of genomic DNA on every continent.

A group of 18 scientists held an organizational meeting at the Royal Botanic Gardens, Kew, London, in April 1991 to share country and institutional experiences using *in vitro* biotechnology and particularly cryostorage of DNA and DNA-rich materials (Adams and Adams, 1992). Relatively few scientists were interested in a "genetic insurance policy" when the idea of banking genomic DNA from plants was first proposed (Adams, 1988, 1990). However, currently 40 institutions (representing 25 nations and every continent, see Appendix I) have expressed interest in DNA Bank-Net (Figure 1).

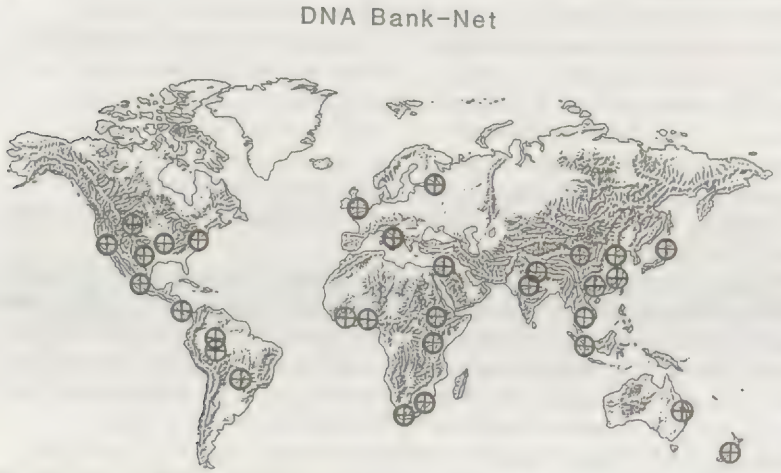


Figure 1. Map of individuals/institutions currently interested in DNA Bank-Net.

The conserved DNA will have numerous uses: molecular phylogenetics and systematics of extant and extinct taxa; production of previously characterized secondary compounds in transgenic cell cultures; production of transgenic plants using genes from gene families; *in vitro* expression and study of enzyme structure and function; and genomic probes for research laboratories.

STRUCTURE AND OPERATION OF DNA BANK-NET

At the organizational meeting of DNA Bank-Net, a task force was convened to define the functions of working (DNA dispensing) and reserve (base) nodes in the DNA Bank network. The group recommended the following functions (Adams and Adams, 1992):

Working (DNA dispensing) nodes:

a. Collection of plant material by taxonomists. This may be the primary function of a particular node or be in association with other organizations such as universities, botanic gardens, etc.
b. DNA extraction by molecular biologists or trained staff.
c. Long-term preservation of DNA-rich materials and/or extracted DNA in liquid nitrogen.
d. DNA analysis/gene replication by molecular biologists or trained staff.
e. Distribution of DNA (genes, gene segments, oligonucleotides, etc.).

Reserve (base) nodes:

a. Long-term DNA preservation in liquid nitrogen and monitoring of potential DNA degradation.
b. Act as genetic reserve buffer for working nodes.
c. Replenishment of DNA if a working node experiences the catastrophic loss of storage parameters and DNA.

GENERAL REQUIREMENTS FOR NODES IN THE DNA BANK-NET

The task group recommended (Adams and Adams, 1992) that the following were the minimum requirements for nodes:

Working (DNA dispensing) nodes:
Personnel: Taxonomists/collectors, biochemists/molecular biologists, technicians for practical work, capable administration.
Equipment: Storage facilities (liquid nitrogen, cryovats), extraction facilities (centrifuges, gel electrophoresis, UV spectrophotometer, etc.), DNA analyses and PCR duplication (PCR thermal cycler, micro-centrifuges, etc.), distribution system (packaging and mailing supplies), computer (database for inventory and correspondence).

Reserve (base) nodes:
Personnel: Technicians, capable administration.
Equipment: Storage facilities (liquid nitrogen, cryovats), computer (database for inventory and correspondence).

Each DNA collection should be split initially into at least 2 or 3 portions. One sample (DNA-rich material or extracted DNA) should be stored at a working (DNA dispensing) node and another portion(s) be stored in at least 1 (one), but desirably 2

(two) back-up reserve (base) nodes. The reserve nodes should be in different countries and, if possible, on different continents to safeguard the DNA samples against various natural and man-made catastrophes.

Several general recommendations came from the task groups (Adams and Adams, 1992); these include:

a. DNA should be extracted from cryo-preserved DNA-rich materials only when the DNA is needed. Delaying the extraction has the advantage of letting technology catch up, so advanced techniques can be used as they become available.

b. Working nodes should generally be an existing organization with adequate biochemical expertise and have an associated herbarium. Having an herbarium on site would not be required but a very close, local (in the city) association with a recognized herbarium (Holmgren et al., 1990) is required.

c. For the working as well as reserve nodes, it is necessary to have a strong institutional commitment, not just a personal commitment, in order that the collection be maintained in perpetuity not just for the lifetime of one person who has committed himself to the idea.

d. Consideration should be made concerning the availability of dependable electricity and liquid nitrogen in determining the feasibility of establishing a node.

e. Considerable interest was shown in the concept of storing composite DNA samples (e.g., a composite of DNA from all the legumes in a region, to be used for screening or retrieval of unusual genes).

f. The need for computer and database compatibility was expressed. Given the number of flat file and relational databases that are compatible with dBASE, it would seem that dBASE compatibility would be desirable. No consensus was reached in regards to this or on the use of a flat file vs. relational database. It was felt that the critical issue at present was to begin collecting DNA-rich materials.

SCOPE OF PLANT COLLECTIONS

The task group given this assignment felt that there is a need for an initial focus rather than random collections and that economically useful plants should be given some priority (Adams and Adams, 1992). However, this priority would not include the major crop plants of commercial usage that are widely cultivated (e.g., maize, rice, wheat, etc.), but rather those indigenous species that are tended and/or otherwise used by local people.

One problem with giving a priority to species is that field collecting then becomes "plant hunting" trips, which tend to be very expensive. It would seem that the cheapest and most practical way to preserve the largest percentage of plant genes would be to utilize the current (and additional) floristic collectors (such as those of the Missouri Botanical Garden, Royal Botanic Gardens, etc.), who are already in the field and familiar with the vegetation in the region. The collection of DNA-rich material (leaves) could be done with little additional effort when specimens are collected.

COLLECTING PROCEDURES

DNA collectors should be considered the same as all other plant collectors. Consequently they should (Adams and Adams, 1992):

a. Voucher all collections in recognized herbaria (i.e., listed in Index Herb. ed. 8).

b. Provide proper label information as to the locality, habitat, etc., for each plant collected.
c. Follow all procedures concerning permits, convenios, and deposition of duplicate vouchers in the country of origin.
d. Collect leaf samples and pack them in desiccants (see Adams et al., 1992) immediately (the same day). Leaves are of value as simple long-term storage.
e. In the case of legumes, samples of root nodules should be taken if possible, but kept as a separate accession.
f. If a chemical treatment is used in the field, information should be provided concerning the method and some untreated leaves must be stored in desiccant (see d. above).
g. Fossil plants—When possible, fossil material should be included in DNA Bank-Net. In this case, when destruction of the source material occurs, documentation via photographs and fragments is necessary.
h. Some material may be accessioned from herbarium specimens under control of local curators using current methods of DNA extraction. Herbarium sheets should be marked if sampled for DNA. Herbarium specimens are limited in supply, and their utility appears to be limited to material collected without chemical preservation. Material may be sampled directly from the sheet or the attached specimen envelope if it contains sufficient leaf material (ca. 0.1–0.5 g dry wt.) for DNA extraction.

INTERIM FIELD STORAGE OF SPECIMENS

The problems associated with bringing back fresh or frozen materials can generally be overcome by specialists (e.g., worldwide collections of fresh foliage of *Juniperus* for essential oil analyses and DNA by RPA). However, botanists doing floristic research will likely collect many of the specimens from tropical rare and endangered species. They often collect specimens from scores of different species in a single day. The bulk of material that they have to process and ship requires that any protocol for the collection of samples for specialized needs (e.g., DNA storage/analyses) must be quick, simple, and trouble-free. The generalist collector, working in tropical areas, cannot be expected to preserve hundreds or thousands of collections for months under tropical conditions and then arrange transport through customs, all the while keeping the individual specimens frozen.

Fortunately, at least as far as DNA preservation is concerned, interim preservation in silica gel or Drierite is an effective way to preserve plant materials in the field and/or in transit for several months at ambient temperatures (Adams et al., 1992). Genomic DNA from fresh spinach stored for up to 6 months still contains high molecular weight DNA (see Adams et al., 1992, for detailed discussion).

PROTOCOL FOR FIELD PRESERVATION OF FOLIAGE

Drierite has a water capacity of 10 to 14%, but above 6.6%, the capacity varies inversely with temperature (W. A. Hammond Drierite Co.). One would not want to risk possible rehydration of leaves, so storage ratios should be based on the 6.6% capacity. In lab tests, silica gel absorbed 8.85% of its weight of water after exposure to 100% humidity for 16 h at 22°C. We have found that plant materials contain as much as 92% moisture, so a useful approximation would be to assume the plant is mostly water and use 16 to 20 times the fresh leaf weight for the Drierite or silica gel component.

One can take a supply of empty plastic 35 mm film canisters, which hold approximately 26 g of silica gel, and then weigh out 1 g of fresh leaf material and add it to the canister along with silica gel (or Drierite). We have found that air-dried leaves (suitable for herbarium vouchers) generally contain from 10 to 15% water. Using a robust value of 20% water for air-dried leaves, one can weigh out 5 g of air dried leaves (5 g @ 20% = 1 g water) or 1 g fresh leaves per 26 g of silica gel. This procedure may seem time consuming, but in practice, we merely do a quick check of the leaf area needed to give approximately 1 g (fresh leaves) or 5 g (dried leaves) and then just use that amount of leaf area. For example, for spinach, a 2 x 4 cm fresh leaf area weighs about 1 g. So, one can just cut the leaves into roughly 2 x 4 cm squares and add one square to 20 g of silica gel. For succulent leaves, a slightly different protocol may be used. Liston et al. (1990) removed succulent leaf material after 24 hours in Drierite and placed it in fresh Drierite.

Caution is necessary when field drying of specimens for subsequent silica gel/Drierite storage. We have experienced difficulty obtaining DNA from leaves dried at temperatures higher than about 55°C. In very rainy conditions where high drying temperatures (from butane stoves, for example) are used to dry specimens, it would seem advisable to merely blot leaves free of surface moisture and then place the fresh leaf material directly into silica gel or Drierite. Liston et al. (1990) took 2–5 g of plant tissue and wrapped it in tissue paper to prevent it from fragmenting, then placed it in a 125 ml Nalgene bottle, 1/3 prefilled with Drierite (with blue indicator crystals), and then filled the bottle (2/3) with additional Drierite. In addition, we have recently discovered that the DNases in some species (especially grasses) can be re-activated if the material is subsequently re-hydrated. The safest procedure is to soak the silica dried plant material in 100% ethanol for 24 h after returning from the field. Then store the material at -20°C until the DNA is extracted.

Plastic bottles are probably to be preferred to glass, to avoid breakage in transit. Using clear jars allows one to check the indicating crystals without opening the jar. The lids should be sealed with vinyl tape to ensure against moisture leakage. The use of parafilm to seal containers is not recommended, as we have found it to come loose at 37°C (and of course, at tropical temperatures!).

Silica gel and Drierite do differ in one characteristic that may be a consideration. We have found that silica gel can be dried (recharged) at 100°C for 24 h, but Drierite must be dried at much a higher temperature (200°C). In addition, we could easily dry silica gel in a microwave oven, but were unable to dry (recharge) Drierite in a microwave oven. If the desiccant gets wet before use, silica gel appears to be much easier to dry. Silica gel is used in large quantities for flower drying and, thus, may be cheaper, depending on the source. Both Drierite and silica gel could be recharged for reuse on subsequent trips, but one should be very careful to remove any leaf fragments. If the materials are to be checked through customs, it is useful to have a small container of silica gel/Drierite that you can open and show the customs agents. A demonstration that the blue indicator crystals will turn pink when you breath on or moisten them is helpful in convincing the customs officials **not** to open your sealed specimen jars.

FUTURE DIRECTIONS

The vast resources of dried herbarium specimens may hold considerable DNA that would be suitable for PCR. It seems likely that the integrity of DNA would decrease with the age of specimens. Because there are many types of herbaria storage, preservation and collections, there is a need for systematic investigations of the effect of

modes of preparation, collection and storage on the integrity of DNA in the world's major holdings.

One of the major concerns in storing DNA from extinct species is the limited amount of DNA available for distribution. A general process by which the DNA could be immobilized and then specific genes or oligonucleotides amplified is needed. Research and development is needed to perfect the system whereby by Kadokami and Lewis (1990) immobilized cDNA from spiders (*Nephila clavipes*) onto nylon and then amplified sections of it by PCR. In a DNA Bank node, amplification would involve removing the membrane with the bound DNA from cryo-storage and amplifying the desired gene, washing away the primers, and placing the bound DNA back into cryostorage.

CONCLUSIONS

DNA Bank-Net is an association that fills a needs for a professional organization that would function initially as a lead organization and superstructure. The association brings together capabilities and expertise, produces a newsletter, and coordinates DNA banking activities.

Technical workshops need to be conducted in order to bring experts together and develop specific techniques and protocols for DNA extraction, amplification, and storage. DNA Bank-Net supports the concept of using license agreements and/or contracts that insure that there is a flow of money back to the countries and/or institutions when commercialization of protected germplasm is achieved. This will guarantee the uninhibited exchange of germplasm for scientific purposes, so that scientific achievements are not obstructed.

DNA Bank-Net should complement activities already being performed by different institutions, specifically, those working in the area of germplasm collection and conservation.

Technically, all the necessary expertise is available to begin the collection and storage of DNA from endangered species. Now, the vision is needed.

ACKNOWLEDGMENTS

DNA Bank-Net has been supported by funds from Baylor University (President's Fund), the Conservation, Food and Health Foundation, the Helen Jones Foundation, and the Wallace Genetic Foundation.

REFERENCES

Adams, R.P. 1988. The preservation of genomic DNA: DNA Bank-Net, AIBS Meeting, Aug., Univ. of California, Davis, California.

Adams, R.P. 1990. The preservation of Chihuahuan plant genomes through *in vitro* biotechnology: DNA Bank-Net, a genetic insurance policy. *In*: Third Symposium on Resources of the Chihuahuan Desert Region, A.M. Powell, R.R. Hollander, J.C. Barlow, W.B. McGillivray and D.J. Schmidly, eds. Printech Press, Lubbock, Texas.

Adams, R.P. and Adams, J.E. 1992. Conservation of Plant Genes: DNA Banking and *in vitro* Biotechnology, Academic Press, New York.

Adams, R.P., Do, N. and Chu, G-L. 1992. Preservation of DNA in plant specimens by desiccation. *In*: Conservation of Plant Genes: DNA Banking and *in vitro* Biotechnology, R.P. Adams and J.E. Adams, eds. Academic Press, New York.

Hawkes, J.G. 1979. Genetic poverty of the potato in Europe. *In*: Proceeding of the Conference: Broadening the Genetic Base of Crops, A.C. Zeven and A.M. van Harten, eds. Wageningen, Netherlands, 3–7 July, 1978. PUDOC, Wageningen.

Holmgren, P.K., Holmgren, N.H. and Barnett, L.C. 1990. Index herbariorum. Part I. The Herbaria of the World, ed. 8. Regnum Veg. 120.

Kadokami, Y. and Lewis, R.V. 1990. Membrane bound PCR. Nucleic Acid Res. 18: 3082.

Liston, A., Rieseberg, L.H., Adams, R.P., Do, N. and Zhu, G-L. 1990. A method for collecting dried plant specimens for DNA and isozymes analyses, and the results of a field test in Xinjiang, China. Ann. Missouri Bot. Gard. 77: 859–863.

Newmark, P. 1987. Trypsin inhibitor confers pest resistance. BioTechnology 5: 426.

Plucknett, D.L., Smith, N.J.H., William, J.T. and Murthi Anishetty, N. 1987. Gene Banks and The World's Food, Princeton University Press, Princeton, New Jersey.

Redden, R.J., Singh, S.R. and Luckefahr, M.J. 1984. Breeding for cowpea resistance to Bruchids at IITA. Protection Ecol. 7: 291–303.

Ullstrup, A.J. 1972. The impacts of the southern corn leaf blight epidemics of 1970–1971. 1 Annual Review of Phytopathology 10: 37–50.

PLANT CONSERVATION IN AFRICA: POLITICAL AND ECONOMIC REALITIES

W. A. Rodgers
GEF Biodiversity Project, P.O. Box 1041
Arusha, Tanzania war@twiga.com

SUMMARY

While there is a great amount of literature on the scientific niceties of plant conservation, we are not winning the conservation battle. Plant resources are being lost faster than we can document them, let alone save them. Why? The basic truth is that conservationists do not conserve or make the basic fundamental conservation decisions. First, these decisions are made by people at the grassroots level: the person with an ax or a hoe. The question is, "Should I or should I not cut this plant?" At a deeper level the decisions are made by the local and national political and economic leadership, who by their policies affect the decision to cut or not to cut. Land-use planning, incentives, disincentives, alternative resources, conservation measures such as reserves, increasing awareness, etc., are all key inputs into the conservation equation. Local decisions are affected by international decision makers (structural adjustment forces in Tanzania have led to districts sacking all forest staff).

The Earth Summit at Rio in June 1992 gave renewed hope that world leadership saw the need for much greater input to resource conservation. At the Convention on Biological Diversity, the Forest Principles all stressed the importance of plant cover to mankind (with values ranging from carbon sequestration to medicinal plants). Most countries ratified the convention promising greater efforts of activity and greater levels of funding. The recently concluded World Summit "Rio Plus 5" has shown how hollow most of those promises have been. The developed world has reneged on funding pledges, with funds in the past 5 years being *less* than that before Rio! Developed nations continue to pollute, to exert pressure on tropical resources, to demand debt repayments, meaning many developing countries cannot maintain even past levels of resource protection. World levels of deforestation continue to increase (especially so when using biological criteria of forest). Developing countries still have soaring populations dependent on land-based resources, agricultural practices are poor, and so new forest land is in demand. Clearing takes place despite the presence of resource conservation policies and legislation. Illegal use is rife, agencies have reduced capability to prevent such loss. Value systems still do not support basic soil, water, and vegetation resources.

What then is the answer? There is no single easy answer. We will continue to lose plant resources at community, species, and genetic levels. One part of the answer is to prioritize so that we do not lose the essential bits (do we know what is essential?). Yes, we know the most important "hot spots" for natural systems and crop relatives. A second part of the answer is for greater synergy for scientists to communicate more with field conservationists and for both to temper conservation demands with realism and learn to speak in social and economic terms that attract the attention of the real decision makers—those on the ground and their political leaders.

INTRODUCTION

Issues affecting plant genetic resource conservation

The global literature on both sustainable development and on the conservation of natural resources, highlights the essential role of natural vegetation in maintaining human well being. Vegetative cover maintains water, soil, climatic stability, etc., and provides fuel, food, and many other essential products (Myers, 1991; Davis et al., 1994). There is a growing body of scientific evidence of the need to conserve this resource at genetic, species, and community levels (Frankel et al., 1995). Despite this concern, resources continue to degrade.

The proceedings from this DNA Bank-Net workshop in Nairobi have an overall emphasis on the genetic level of plant resources, but by and large genetic resources are maintained through the conservation of the individuals, populations, and taxa (species) in which they occur. Species conservation is achieved through the plant communities or habitats in which they are found; we maintain the communities by safeguarding the land on which the community occurs. Land is thus the fundamental unit of conservation. Land-use is usually decided by economic criteria, and land ownership is often decided through political argument. The interactions between plant conservation, economics, and politics form the basis of this paper. As a biologist and conservationist, I have come to realize that the real decisions about conserving a resource, an area, or a species are political decisions assessing the economic implications of that decision.

Countries have endorsed the need to conserve vegetation and plant resources through their ratification of the Global Convention on Biological Diversity (Swanson, 1997). Despite this acceptance of the need to maintain vegetative cover, there is an increasing loss of natural forest, grassland, and other vegetation types all over the world (FAO, 1993, 1994; UNEP, 1995; WRI, 1990; Jepma, 1995; Rodgers, 1993, 1995). Conservation action on the ground does not seem to follow from the conservation rhetoric that is expressed at international and national forums.

Plant conservation is a part of a broader environmental debate. There are several signs that today, five years after Rio, we are losing the environmental battle: there are less funds; there is increasing backlash against conservation in both the developed and underdeveloped world; and there is decreasing commitment by governments and their leaders (Lake, 1996; James and Green, 1997). Plant conservation is a large part of the biodiversity issue (globally "governed" by the Global Convention on Biological Diversity), but maintaining an adequate vegetative cover is also important to the Forest Principles, the Global Warming (Greenhouse gas) Convention, the Desertification Convention, etc.

Why does this state of affairs continue to exist? If the conservation of resources is so important, then why is it not being done? This is the same argument as that put forward for wildlife resources in East Africa (Norton-Griffiths, 1996).

Governments have policies and laws in place to protect resources, and yet they continue to be degraded and disappear. What causes policy failure? On a more practical note, what must we do to ensure that policies do not fail in the future?

Conservation arguments for utilitarian resources stem largely from the people-support organizations (donors, NGOs) and, for biodiversity values, from the scientific lobby, increasingly organized into advocacy groups (Society for Conservation Biology-Brussard, 1994). There is now an enormous amount of literature explaining why we should conserve, where we should conserve, and how we should conserve. Despite this knowledge we have not been able to conserve.

We are beginning to realize that different segments of our society (the rich, the poor; the local people, the city dwellers; the developed and the developing worlds) pay different costs and receive different benefits from conservation. Our new conservation modalities only now start to address the issue of equity within the conservation movement.

POLITICS AND ECONOMICS—THEIR LINKS TO CONSERVATION

"Politics" itself rarely poses the problem faced by conservationists; it is those who practice politics, the politicians, who cause the trouble! Politicians, especially in the developing world, have the ultimate say over resource use. It is the politicians who determine policies and laws governing such use. While in the developed world the bureaucracy has a great say in interpreting and implementing those laws, the developing world has a bureaucracy that is much more controlled by political forces. Third-World politics is increasingly about staying in power. Staying in power requires money to buy votes. Forests and land are resources that can be sold for votes.

"If India had elections every year, there would be no forests left," said the late Rajiv Gandhi in 1994 before he became Prime Minister of India. Politicians operate at local levels (village and district governments with elected leaders), national levels (national governments), and international levels (via global conventions, patterns of aid and trade, etc.). Politicians seek re-election every 4 or 5 years, and so political vision is usually a short-term process, whereas conservation requires a long-term time span. Conservation is often seen as a conflict between local people who want to use or convert a resource, and external forces (the conservationists) who want to reduce the rate of use. Politicians are elected by the people, and so find it difficult to argue for what may be a national good if it causes a local loss of votes.

Government ideally is the arbiter between public good (what is needed in the public interest: continued water supplies, clean air, recreation) and private good (where an individual or business wishes to use a resource or convert that resource for profit). However, in the developing world it is common to find that leaders of government (the politicians) are also the private business developers. Checks and balances break down.

"Economics" rather than economists is the problem facing conservationists. Economics is a decision-making tool (cost/benefit analysis). Unfortunately the tool is still loaded in favor of monetary profit from resource use. We are still learning how to value plant resources and vegetative cover. What is the value of wild crop relatives and of forested watersheds? Economics also looks at mechanisms to encourage conservation-economic instruments of subsidies, incentives, and disincentives. A tax subsidy on kerosene can reduce demand for fuelwood. Increased electricity tariffs can lead to increased fuelwood use, and thus deforestation. A financial incentive to grow trees can rapidly change landscapes; crop subsidies encourage vegetation clearing.

The process of Environmental Impact Assessment (EIA), another part of economic reasoning, also concerns conservation. EIA asks "What would happen if....?" What would happen: ...if this forest were felled? ...if this marsh were drained? ...if this factory effluent came here? ...if this level of harvesting was to continue? EIA should examine projects and development proposals (the normal practice), but also examine new programs, policies, and laws: "What will be the impact on forests if agricultural subsidies for land clearing continue?" These deeper analyses are rarely undertaken.

Economic reasoning becomes more complex when one compares local, national, and global benefits. Reducing local people's use of a forest to maintain water supplies to a distant city is a difficult decision. The key to environmental success is determining

how both sides of the argument can gain (i.e., developing a win-win situation). At a global level, how do conservationists argue that a country should reduce the rate of forest clearing as it is in the world's interest (read Western world!) to keep that forest for intangible biodiversity values? There has to be some form of compensation. The GEF (Global Environment Facility) is to provide funding for such compensation, paying the so-called incremental cost of providing global benefit.

It is interesting that many papers at this DNA Bank-Net workshop mentioned the need for continued donor support to maintain gene banks, land races, and to fund plant resource exploration. It is difficult to separate what is a national and what is a global benefit in maintaining wild sorghums, for example. Certainly given Third-World financial constraints, such activity is very low on national priorities.

"Conservation" is increasingly a generalist word, with several different meanings. These include the derogatory "anti-development" usage (witness the Harare CITES meeting in June 1997); this perhaps derives from the strong "preservation at all costs" message of some conservation groups. There is also the technical usage associated with maintaining energy and gene flows, and the more human-oriented "wise use of resources." The Convention on Biological Diversity recognizes three sets of activities necessary for conservation: the maintenance of the resource, the sustainable use of the resource, and the equitable sharing of benefits from that resource. Conservation is therefore a generalist goal, and is linked to sustainable development—another nebulous concept. There is no way the world can maintain all remaining resources in the face of continued growth of population and consumerism. Conservation is thus beset with questions: "How much to conserve? What does sustainable mean? What value can we attach to a forest? Who should share the benefits and how?"

Conservation in the past was a "command and control process." Do this. Do not do this. Stop cutting or collecting or clearing this resource, etc. This area is closed to you; it is a national park or reserve (used by foreigners not by locals). Increasingly this strategy was seen not to work unless coupled with huge protection budgets and increased conflict. Why should people stop doing that? What is the incentive? Often, even more fundamentally, what is the alternative? The poor have no alternative but to use fuelwood or charcoal; often their only income is from such exploitation. As a result of past failures, newer conservation ideas are more people-oriented, involving benefit sharing or even shared resource management and ownership.

A recent breakdown in government in many Third-World countries has worsened the conservation problem (Deacon, 1994; Jepma, 1995; Juma and Ojwang, 1996). Regulatory agencies collapsed as wages became worthless (Howard, 1992) and operating funds dried up. Loss of government meant that private gain usurped public good. Traditional communal conservation mechanisms broke down. Local government became more corrupt. Conservation became less of a priority.

This paper has mentioned the issue of private versus public cost and benefit, as well as global versus local cost and benefit. These issues are important both in theory (how can one apportion benefit from a forest into global and local benefit?) and in practice. In practical terms there is a need to examine how Third-World countries can invest in conservation when repayment of past foreign debt requires up to 50% of GNP. Forest conservation may be an obvious public good to the West, but why is the rate of boreal forest loss higher than that in the tropics (Rosendal, 1995)? Why is it not obvious to Brazil, Congo, or Malaysia! Table 1 shows the pattern of benefit flowing from plant resources; most is national or local in nature.

Table 1. Biodiversity values: Local or global in nature?

1. Ecosystem Functions (catchment/soil processes, nutrient cycling)—benefit the host country.
2. International Export Values (timber, beeswax, tourism, medicines)—benefit the exporter.
3. National Market Products (fuel, timber, water)—benefit national economies.
4. Local Market Products (food, poles, local medicines)—benefit local economies.
5. Household Products (food, fuel, poles, cultural, etc.)—benefit local people.
6. Global Intangible Values (carbon fixation, science).

It is the last category that is truly global. The others provide benefit to nations, communities, and individuals. Ecosystem functions can have global importance, e.g., resilience, global warming (Mittermeir and Bowles, 1993).

THE CONSERVATION PROBLEM

Sharma (1992) summarized information on forest and woodland resources. In the 1980–1985 period, forest was lost at an annual average rate of 11.4 million ha or 0.6%. Now it has almost doubled to 18.5 million ha or 1% per annum (FAO, 1993; WRI, 1990). It is the rate of acceleration of forest loss that is critical. Are we still losing forests at an ever increasing rate?

Jepma (1995) described the FAO and WRI data sets as the "forestry sector view," with forest loss defined as the complete clearance of tree formations and their replacement by other land-uses (i.e., forest loss is land that is lost to forest sector's control). Several authors argue that this excludes the loss of closed forest (which is the real focus of biodiversity interest) degrading down to a more open woodland, and so losing the function of a forest. These arguments led to the scientific lobby producing different definitions, where deforestation usually includes severe degradation. Myers (1991) produced the broadest data set from this lobby.

Table 2 shows the extent of forest loss as assessed by these reviews. Note that the different definitions of what is forest cover, and so what is forest loss lead to major discrepancies in amounts and rates. These different definitions of deforestation present

Table 2. Forest cover and rate of forest loss in the tropics.

REGION	FOREST AREA ESTIMATES			ANNUAL LOSS %		
	WRI	FAO	Myers	WRI	FAO	Myers
Tropical Africa	4.6	3.5	0.5	0.5	0.7	1.0
Latin America	7.8	8.2	3.9	1.4	0.6	1.7
Tropical Asia	2.7	2.3	1.9	1.0	1.4	2.2

Area Estimates are in million sq. km. Data from: WRI (1990) early 1980s—total of open and closed forest; FAO (1993) for total forest area (>10% canopy) in 1990; Myers (1991) for total closed forest in 1991. See Jepma (1995) and FAO (1995) for discussion.

problems when attempting global overviews of forest loss. They prevent analysis of causes of problems at the national level, and prevent the monitoring of the efficacy of solutions. Forests are a national resource, and policies that cause or prevent forest loss are largely national in their design and their implementation. Action therefore has to be around national databases and national monitoring activities. There are few factual data

at the national level. In Tanzania, for example, there is a rule of thumb figure of 400,000 ha deforestation per annum, but there is no basis for this estimate. (FAO data are developed from continental averages for Tanzania, as there has not been two sets of forest cover mapping.) It is not possible to break down this crude figure as to where this deforestation takes place, or on what sort of land, or why. Of fundamental interest is the legal status of the site from where such loss occurs. Are we seeing loss from open unreserved forest (which is to be expected), or is there also significant loss within the protected area networks (from where loss is not expected to take place)?

Why are we losing forests? Most national forest policies state that forest resources should be conserved, and yet we see increasing levels of degradation. The causes of deforestation are not well understood. Discussion often mixes the direct causes (e.g., slash and burn agriculture) with the underlying fundamental or **root** causes of loss (Sharma, 1993; Pearce and Moran (1994), introduce the issues in economic terms). Underlying causes include market and policy failures, population growth, and rural poverty, which lead to land conversion, etc. Table 3 summarizes the direct reasons for forest loss.

Table 3 Analysis of direct reasons for forest loss.

Burning/clearing for cultivation	63%	Conversion to commercial agriculture	16%
Felling for firewood	8	Reclamation for livestock ranching	6
Commercial exploitation of timber	6	Construction of infrastructure	1

Note: These are figures are for total loss, not degradation.

Deforestation and forest degradation, particularly in developing countries, are influenced by an array of structural problems related to the international economic regime as well as the underlying socioeconomic features of the country itself. It is useful to consider two levels of underlying or root causes:

- The ultimate factors themselves, about which we can do relatively little in the medium term:
  - Population growth and resource demand
  - Economic dependence on natural resources
  - General widespread poverty
- The proximate factors, which can be addressed in the medium term:
  - Inadequate policy regimes
  - Lack of stakeholder participation
  - Lack of adequate tenure and access rights
  - Inadequate investment in the forest sector
  - Inappropriate valuation systems
  - Inadequate land-use planning capacity and systems

Why are forest conservation (meaning rational sustainable utilization) policies failing? Is it the failure of policies themselves? Most tropical countries have some form of forest policy; it is not a policy vacuum. Or are the policies poorly implemented? Policies exist at several levels in government. Most are sectoral in nature, reflecting the separation of responsibility within most government systems. For example, in Anglophone Africa most governments have forest, wildlife, energy, environment, land, population, water, agriculture, and policies etc. Usually there is little linkage between them; sometimes they are non-compatible! These sectoral policies should fall under the general economic and development policies of the country (at a simple level the degree

of "isms" of socialism or capitalism, the dependence on subsistence agriculture or an increased industrialization; private venture or state driven, etc.).

Conservation is thus about land and the political and economic forces that dictate the use of that land. Four case studies illustrate the interplay of politics and economics with conservation.

Case 1. City Forest in Nairobi, Kenya.

Nairobi City has a relict patch (several hundred hectares) of a once widespread but now greatly restricted forest type: *Olea-Brachylaena* dry forest. City Forest is a national forest reserve, but has been subject to a number of remappings in recent years, ostensibly in the public interest, but in reality to private business gain. Remapping (i.e., notification in the Government Gazette) is done by political action. The public loses access to recreation facilities, and loses green space in an increasingly polluted city. Politicians and businessmen gain. Action to reverse such change is hampered by the loss of land registry titles, etc.!

No strong conservation campaign has protected this forest to date, and the situation is politically complex, involving city and national institutions. The level of political input has reduced the role of regular forest protection, and so hastened the forest's clearance.

Case 2. Montane Grasslands in the Drakensberg Mountains, Lesotho.

Lesotho's mountain grasslands are extremely rich in plant diversity, with many endemic species. Serious overgrazing leading to lost vegetation and soil cover was first noticed in the 1930s and has worsened continuously since then. Lesotho has Africa's lowest Protected Area coverage (<0.2%), and investment in conservation through destocking proposals, etc., have failed. The reason is in the communal land tenure system. All grazing land is open to any Basotho to use, ostensibly at the discretion of hereditary chiefs. The lack of longer-term ownership, and the great mixture of simultaneous use, prevents private or adequate communal conservation measures.

Conservation requires a change in land and resource tenure systems, both political issues. Reduced access will also require some form of compensation. The plans for Lesotho to divert water from the Orange River to the Vaal River for South African industrial consumption in return for over $50 million (USCY) annual royalty could provide the basis for that compensation—now an economic argument.

Case 3. The Kazimzumbwi Forest Reserve in Coastal Tanzania.

Kazimzumbwi Forest Reserve in the Coastal Region lies adjacent to the rapidly spreading Dar es Salaam City. Situated on the first rise from the sea, the land is potentially very valuable for development. The once rural villages bordering the reserve now contain large numbers of immigrant city dwellers, and land is in short supply. The past four years have seen increasing levels of illegal deforestation within this small (2000 ha), but biologically rich forest. In 1993 villagers who cleared forest and planted crops were arrested and fined $6 each. One villager appealed, and as the local forest officer mysteriously failed to show evidence that the land was reserved forest, the appeal was upheld. This the villager interpreted as license to continue to deforest, and he and the village committee sold forest land (and copies of the court judgment!). Several hundred hectares were so cleared. Government appealed to the highest court,

and the decision took over two years. During this time the local Member of Parliament said he could not take action as it was election year (you do not get elected on a conservationist stance!). A national NGO, The Wildlife Conservation Society of Tanzania, championed the cause of the forest, with financial support from the Global Environment Facility, and invited successive Directors of Forestry and at first the Deputy Minister and the full Minister of Natural Resources to the site. Speeches were made banning clearing and police stayed at the site for a few days, but nothing happened. The Appeal Court then upheld the earlier ruling on the grounds that the government gave the wrong forest name! Again this was license for the original appellate to continue felling.

Arrests of other people clearing the forest provoked "senior people" to lobby the Ministry to stop this persecution. Villagers threatened to burn political party cards if government and NGO continued to harass people. The situation became one of which a legal forest reserve was being systematically cleared within full view of a seemingly powerless government some 20 kilometers away!

The NGO and Ministry eventually lobbied the vice-president, with new jurisdiction for environment, to intervene. This the vice-president did, with immediate results. Those deforesting were expelled from the party. National and local government offices were given explicit instructions to prevent further clearing and plant up the gaps. The Forest Reserve was re-demarcated and boundaries again stated in the official gazette.

Here we see a case of political action being the only way to solve a conservation problem; government bureaucracy at local and national levels had failed. NGO support had mobilized the press and political leadership.

Case 4. The Time-Scale of Political Decisions: A Lesson from India.

The Silent Valley in the Evergreen Rain Forest of the Western Ghats in Kerala, South India, is one of India's most diverse forest communities. It also occupies an ideal site for generating hydropower in an area increasingly short of power. In the 1970s a dam was planned, meticulously so, by the engineers, with all the potential benefits of power and irrigation spelled out (the disadvantages were not listed, of course). The conservation lobby took up the case, without the benefit of a world or national audience believing in biodiversity, without lists of species, endemics, and rarities, etc., and without the benefit of ecological economics. Of course, the conservation movement lost. The dam was approved! Appeals to the then Prime Minister (Moraji Desai) failed. A new Prime Minister, politically strong and increasingly "green" (Mrs. Indira Gandhi), vetoed the project; and the area was declared a National Park. Note that conservation action came through political lobbying.

Today, almost 20 years later, the central government politicians in India are greatly weakened, and Kerala State is even more short of power. The state engineers have recently been on strike demanding that the dam go ahead. Building a dam destroys the forest forever, but stopping a dam is at best a series of postponements. A new political scenario could reverse the past decision. Unfortunately, the conservationists have still not mastered the economic arguments proving the value of undamaged rain forest.

Plant Conservation: The Science and the Practice

The international literature has produced several journals on the conservation of biodiversity, and a series of excellent textbooks on "how to do it." Conservation biology is full of mathematical reasoning on design criteria for reserves (see Spellerberg, 1996), and on algorithms for efficient reserve selection (see Humphries et al., 1992). Unfortunately, few of these texts acknowledge the political realities of on-ground conservation in the tropics, and the importance of the bottom line—the costs and benefits of conservation and who pays and/or receives the benefits.

Vandermeer and Perfecto (1997) compare the different approaches of conservation biologists and agro-ecologists, and discuss how the two forces can usefully combine. "Both sets of practitioners lament the passing of biodiversity, both regard the loss as catastrophic. Both clamor for political and technical action to stem the loss. Yet the discourses of the two are strikingly different, with very different emphasis of action." Vandermeer and Perfecto see this dichotomy as unfortunate, confusing the listeners. They suggest great synergy would come from concerted action.

Agro-ecologists are more pragmatic, interested in ecosystem function and output, especially from managed ecosystems. They are concerned with better management, interested in short-term gains. The conservation biologist has more diffuse "higher order" gains. Aesthetics, ethics, and religion are not infrequently called upon! Concern is with extinction and processes that favor population viability. Hardon (1996) sees the conservation biologist as stressing *in situ* conservation focusing on species. Agro-biodiversity rarely has a species focus, "since their continued existence is seldom threatened." Their main interest is genetic diversity within crops and selected related wild relatives. Traditional "on-farm" agriculturists are interested in these landraces, but for economic survival, not conservation. A landrace is maintained as long as it is useful—now! Such on-farm use of germplasm is similar to the *in situ* conservation concepts of naturalists, but it lacks long-term security as their goals differ.

There is a further gulf between the two camps as most nature conservationists see agriculture as one of the greatest impacts on biological diversity, through conversion, loss of wild germplasm, and chemical impacts. However, the two sides begin to merge in a consideration of landscape-scale processes and a focus on agro-ecosystems. While agriculture does emphasize few high-yielding varieties, at larger scales there is a need for a diversity of input to cater to the diversity of micro-sites. The greater the variation in time or in space at a site, the greater the need for diversity of genetic materials to utilize that site. Harrington (1997), in an extremely thoughtful essay, said:

"However, agro-ecosystem biodiversity is not an end to itself, but a means of achieving productivity, stability, resilience, improved environmental quality and the conservation of crop genetic diversity. These lead to the larger societal goals—sustainable food security, reduced poverty, and improved public health!"

Agro-ecosystem diversity can support natural biodiversity in two ways: directly, as diverse ecosystems will provide habitat for a variety of wildlife, and indirectly, as productive agro-systems make it less necessary to farm marginal habitat. There is a need here for adequate landuse planning systems, or effective fiscal incentives to ensure these objectives are reached.

While there is potentially great synergy from combining conservation activities, unfortunately conservationists are not able to speak with a single voice. The conservation lobby is in itself deeply divided as to goals and the strategies to achieve these goals.

What Do We Want in Terms of Plant Conservation? What is Our Goal?

We want to maintain the values we obtain from plants and plant cover. We want to reduce the forces that reduce the stream of benefits coming from plants. Fine, but what are those values? The value is in the resource base, and these can be categorized:

Direct use values:	timber, fuel, foods, drugs, recreation
Indirect use values:	water flow, pollution abatement, carbon storage
Potential use values:	benefits from plant genetic materials
Complex non-use values:	aesthetic value, option value, etc.

Emphasis on resource values accentuates the use versus non-use debate. Biodiversity conservationists argue for a certain amount of vegetative cover to be maintained without use, as ecological reference points, etc. Biodiversity conservation requires that representative areas of all plant communities or habitats be reserved. Few countries can boast a conservation strategy that sets out a detailed site-based action plan. As a result, we are still unable to state our minimum requirements for conservation, or our priorities for conservation! No wonder we are not winning the conservation battle! We do not have time for academic argument, we cannot wait until surveys enumerate every species in forests to determine which is the richest. The conservation argument is fueled by our concern at the increasing rate of loss. Natural communities are being lost, communities are being degraded, species are going extinct, genetic variation is being lost.

Whole habitat loss is relatively easy to see and measure. It is less easy to see biodiversity loss. All forest or grassland has some biodiversity value, although some areas are much richer than others in communities and species. The loss of any community leads to lost resources, including the loss of biodiversity value. Our concern is, or should be, twofold:

- Preventing the loss and degradation of plant resources, e.g., forests, in general. These resources have a multitude of direct and indirect values: including global values of carbon sequestration, other climatic benefits, and biodiversity, as well as more direct biomass resource uses of value to local economies.
- Reducing the loss of biodiversity values within communities as a consequence of manipulation and use for other benefits (the enhancement of biomass, for example, by conversion of natural forest to a conifer plantation).

Plant Conservation in Africa Today

Virtually all wild plant conservation is achieved through *in situ* means by Protected Areas—National Parks, Game Reserves, and Forest Reserves. Rodgers (1995) discussed the differences between the older resource exploitation concepts governing reserves in the forest sector, and the newer concepts of limited use reserves and community benefits in the wildlife sectors. Plant conservation in Africa is usually aimed at the ecosystem or more rarely, at the community levels. Rarely has conservation addressed the species level, unless for crop relatives (e.g., *Coffea* in Ethiopia). For example, studies looking at the adequacy of conservation efforts have used overviews of vegetation types and their representation in protected area networks (Rodgers, 1993, 1995). As most parks were created for large mammal values, the coverage of vegetation types is extremely variable. Forest, wetland, and coastal communities are underrepresented. More recent attention, as seen in South Africa, has addressed this imbalance, as evidenced by the increasing number of parks conserving parts of the range of the extremely rich dwarf-shrub *Protea fynbos* in Cape Province.

However, institutional problems still affect conservation. Wildlife departments are mandated to conserve the fauna. Forest departments protect the forest communities. Non-forest vegetation without large mammals gets less attention (see Case 5, discussing Kitulo Plateau in Tanzania).

Case 5 Who should Conserve the Grassland Plants of Kitulo Plateau in Tanzania?

Kitulo Plateau at 2700 m in the Mbeya Mountains of southern Tanzania has been described as Africa's Serengeti of flowers. There is an extraordinary diversity of orchids and other herbs, including several endemics. Unfortunately, the area has no conservation status and is rapidly being cultivated for potatoes. The best conserved patches are on a state-run cattle farm, about to be privatized.

The simplest solution would be to extend the adjacent Forest Reserve that protects the adjacent forested slopes—an important watershed. But as it is not "forest," the forest division has no interest. There are no large mammals so the wildlife division has no interest. The area is shortly to be listed as an Important Bird Area (IBA), but such bird values still have a weak institutional base, and IBA status carries little meaning. However, IBA is some recognition. The fact that there are several endemic plant species, and that the site is one of Africa's richest grassland communities carries even less weight. Plant conservation is not yet an issue of concern on the world stage, as for example are birds.

Tanzania still has a separate Government Wildlife Division and a parastatal National Parks Authority. Parks see the area as being too small in which to invest. We have discussed the concept of a "contracted" national park, to be managed by the District or by the village community. But why should the villagers take on this role and deprive themselves of potato land?

Forest reserve status in the past has not led to strong conservation. Reserves can be legally clear-felled and planted with exotics, or heavily logged, or "managed" to achieve "uniformity" by reducing "diversity" with concepts of weed trees, climber and strangler cutting, etc. Recent policy changes stressing multi-purpose and protection forestry as opposed to production forestry can reduce such risk of man-induced simplification and degradation (Rodgers, 1993).

There is little recognition of species value for wild plants in the region. There are 15,000 species of higher plant in East Africa. There are attempts at Red Data Book listings, and there are some extremely rare species, and there are plants collected at the turn of the century and not seen since (presumed extinct?). The African violet (*Saintpaullia*) provides an example, with some 12 threatened species in the coastal and eastern arc forests of Tanzania and south Kenya. Some of these violet species are known from only a few plants in non-protected areas. The African violet is the basis of a huge horticultural industry in the West, most based on one species alone (*S. ionantha*). Tanzania has not shown interest in protecting these plants. NGO efforts are beginning to target the industry itself in the USA, seeking advocacy and funding for conservation. The National Museums of Kenya have used *Saintpaullia* as an example for *ex situ* conservation.

Ex situ conservation efforts in tropical Africa are declining. Botanical gardens in East Africa, unfortunately situated in prime city land, are under growing threat of encroachment, and are little managed. Arboreta are scarcely used. The demand for higher quality tree seed has led to the development of tree seed orchards, but for limited

species, which are often exotics. Withdrawal of donor funding will see a decline in resource maintenance.

The Conservation of Plant Germplasm of Agricultural Importance

Agricultural efforts at conservation are, in theory, more advanced, linked to international efforts and with technical backup from IPGRI, SADC, etc. But on-ground reality shows the paucity of funding and government interest. There is a rapid loss of germplasm. There were hopes that the recent extreme loss of bean germplasm in Rwanda would act as a stimulus for greater conservation efforts in neighboring countries, but this is not yet obvious. Debate in conservation matters has concentrated on equity issues, farmers' rights versus breeders' rights, rather than on-ground practicalities. Hardon (1996) lamented the takeover of the resource-oriented discussion forum, e.g., the Convention for Biological Diversity (CBD), and Global Plan of Action for Plant Genetic Resources (GPA-PGR), by political forces:

"As often in UN meetings, the subject has become dominated by policy makers and politicians, leaving biologists and agriculturists who raised the original alarm over genetic erosion perplexed and on the sidelines. The debate has become concentrated on issues regarding control and ownership of PGR. These political and economic problems are real, however genetic diversity is being lost at an ever increasing rate!"

While I sympathize with these sentiments, I do not agree that this is a problem; it is the beginning of the solution. If conservation is to succeed, then it needs political support. Politicians have joined our technical forum; it is up to us to join them at their game, and couch our biological agenda in political terms. In Tanzania, we have tried to "Put Environment on the Political Agenda" (WCST, 1996). The Convention (CBD) and WorldBank call this "Mainstreaming Biodiversity" (e.g., Secretariat-CBD, 1996a,b).

The Conservation of Genetic Diversity in Tropical Forest Ecosystems

Biodiversity conservation is not only species and the ecosystems that contain the species, but also the genetic variation within these species (e.g., Kemp and Palmberg-Lerche, 1994). Genetic diversity in forest ecosystems, the variation within and between species, provides:

- the basis for their adaptation to environmental stress, including more extreme effects of global climate change in the future, and emergence of new pests and diseases; and
- the basis for sustainable development and improvement of forest resources for human use. Such improvement is an urgent need as human populations grow in size and in their demands.

Increased forest productivity will depend on the selection of superior genotypes; there is a need, therefore, for a broad genetic base. Standard conservation procedures of creating protected areas to maintain species and ecosystems may not be enough to maintain genetic variation. Several populations of a species should be maintained, preferably covering the geographical and environmental limits of the species range. Highest levels of genetic variation often occur at the edges of a species range: unfortunately, these edges are often most vulnerable. Genetic conservation therefore requires a network of PAs across the species range, within a mosaic of other land uses where examples of target species may be found. If needed, *ex situ* methods (e.g., seed orchards, etc.) should be used. An example of a species distribution study that allows the planning of genetic level conservation is that of *Juniperus procera*—pencil cedar (Hall, 1984).

While some may see genetic impoverishment as the least damaging form of biodiversity loss, this is the loss that is related to resources of proven value (wild crop relatives, timber tree provenance's, etc.). It is access to such genetic variation that drives the global debate on access to biodiversity (Juma, 1989). Genetic impoverishment is the least obvious: it is difficult to detect visually, but that is not to say that it is not important.

Policies for Plant Conservation

Plant conservation should not be, and cannot be, a means or an end in itself. Plant conservation is an integral part of environmentalism, and the movement toward sustainable development. Sustainable development has a great dependence on a productive plant base, for resources, on the continued flow of water and fertility of soil, and on the biological diversity inherent in these resources. Biodiversity conservation is, or should be, a goal of many sets of policies including: agriculture, water, energy, and natural resources. Policy statements are, however, trite, and deal with the surface of the problem: "create protected areas," "ensure people's participation," "allow only sustainable use." What is missing is how to achieve to such goals. Linking policy to practicality is an often missed, essential step. A strategy is necessary.

The first functional component of the Global Convention on Biological Conservation is the need for each nation to have a biodiversity strategy and action plan; such a strategy would be governed by key policy statements. These statements go beyond the obvious of protected areas and participation. Barrett (1996) argued that key elements of a biodiversity policy that would lead to a strategy and action plan would be (my italics):

1. Social resources (i.e., public funds) should be directed toward protecting biodiversity that would otherwise not be protected. *Prioritize; do not protect land of marginal value; do not conserve land protected by other means. Do not invest in Serengeti (tourism will do that; invest in Kitulo Plateau instead).*

2. Policies must have an objective. Why are we protecting this? And for whom? The specific type of biodiversity to be protected must be defined. *This means knowing what ecosystem, species, genetic value, landraces, etc., are valuable. Prioritization needs objectives to work towards. One suggestion is that global policy should be to protect internationally recognized hotspots as the first priority. The level of protection (how much area) and degree of protection (how much use) need specification.*

3. Policies must seek to reach their desired objectives at minimal monetary and social costs. *Funds are scarce, therefore invest wisely. You get more "bang per dollar" or more critical species conserved per hectare or dollar in the hotspots—the centers of diversity and endemism. There is also opportunity cost. All else being equal, protected areas should be in areas where land has little alternative value or use. Most PAS are so located (by default). However critical gaps are on fertile lands, including many forested areas. The reduction of social costs through alternative resources and other incentives is also important.*

4. Policies should address the conflicts between national and personal (private) interests, and seek to prevent such conflict. *The complexity of market distortions apply here. Externalities are more than lost opportunities, and market failures need consideration. There are considerations of equity and access to consider. Equitable conservation in a society which in itself has poor governance and high-level corruption over land is not possible.*

5. Policies should address conflict between national and global interests, and seek to prevent such conflict. *Biodiversity has global public good, attributes, aesthetic values, and potential values. There needs to be greater dialogue over ways for global needs to pay their share of costs.*

These are largely societal issues, and are in the realm of political decision making rather than biology. It will be the biologists and conservationists who have to lobby for political decisions. The ball is in our court. Hardon (1996) looked at linkages between CBD and the Plant Genetic Resources (PGR) debates. He saw policy issues including maintaining genetic collections as public goods, intellectual property rights, integration of farmers *in situ* holdings into national *ex situ* conservation efforts. Many of these issues have been formulated into the Global Plan of Action for Plant Genetic Resources (FAO, 1996).

The starting point is the Convention on Biological Diversity, which governments signed and ratified (with varying degrees of debate and understanding of the commitments it entails.). Swanson (1997) described the CBD as a framework for action, rather than a set of actions. The actions to implement this framework still need to be developed. Swanson proposed a series of protocols to stimulate action. These dealt with land-use, financial transfers, and further inter-nation agreements, etc. These, too, are political decisions—not biological.

Rarely do developing countries (or any other) have such articulate policy statements or the start of protocols. National policies are typically generalities, both naive and non-measurable; "biodiversity will be conserved...." Often the policies come out of technical departments and ministries, developed by technocrats with little political or economic support. To date they have not worked.

The attention of the Conference of Parties (COP) for the Convention for Biological Diversity focused the attention of Articles 6 and 8 on national policies, strategies, and plans, etc., for resource conservation. Future work should increasingly focus on relevant sectoral and cross-sectoral plans that impact on biodiversity (Secretariat-CBD, 1996a,b). From here, emphasis in sustainable agriculture and agro-biodiversity become urgent matters. Article 9 seeks integration of biological diversity into agriculture to stimulate the transition to sustainable agriculture. Again we see the need for synergy between the PGR conservation lobby and those interested in natural conservation.

CONCLUSIONS

Land, the basis of plant conservation initiatives, is a scarce resource. The value attached to such scarcity provides the bottom line for the conservation argument: votes and money control the land-use decisions in Africa, not science or international concerns. In the developed world, conservation can attract votes; but even there when money (jobs) are at stake, anti-conservation forces will win. The old-growth forest and spotted-owl debate in the Pacific Northwest of the United States, and the Sites of Special Scientific Interest (SSSIs) and motorways in the United Kingdom are immediate examples.

In the tropics of Africa, conservation measures can lose votes, and so it is not a political priority. Many people have no alternative but to continue land-use practices that seriously impact on plant biodiversity and the environment. Conservation is therefore going to have to find alternative development strategies that emphasize sustainability. This, with almost 3% population growth, seems ever more a pipe dream.

REFERENCES

Barrett, S. 1996. Economic Development and Environmental Policy. FAO Economic and Social Development Paper 138. FAO, Rome.

Brussard, P. F. 1994. Why do we want to conserve biodiversity anyway? President's Column. Conservation Biology Newsletter 1(4): 1.

Davis, S. D., Heywood, V. H. and Hamilton, A. C. 1994. Centers of Plant Diversity. WWF and IUCN. IUCN Publications Unit, Cambridge, UK.

Deacon, R. T. 1994. Deforestation and the rule of law in a cross-section of countries. Land Economics 70(4): 414–430.

FAO. 1993. Forest Resources Assessment 1990: Tropics. FAO Forestry Paper 112. FAO, Rome.

FAO. 1994. Forest Resources Assessment 1990: Country Briefs. FAO, Rome.

Frankel, O. H., Brown, A. H. D. and Burdon, J. J. 1995. The Conservation of Plant Biodiversity. Cambridge Univ. Press, Cambridge, UK.

Hardon, J. J. 1996. Conservation and use of agro-biodiversity. Biodiversity Letters 3: 92–96.

Harrington, L. 1997. Diversity by design. CGIAR News 4(3): 5–8.

Hall, J. B. 1984. *Juniperus procera* in Africa: a biogeographical study of an Afromontane tree. J. Biogeogr. 11: 47–61.

Howard, P. 1992. Nature Conservation in Uganda's Tropical Forest Reserves. IUCN, Switzerland.

Humphries, C. J., Vane-Wright, R. I. and Williams, P. H. 1992. Biodiversity Reserves: Setting New Priorities for the Conservation of Wildlife. Natural History Museum, London, UK.

James, A. N. and Green, M. J. B. 1997. Financial Indicators for Biological Diversity Conservation: a Global Analysis of Protected Area Investment. WCMC, Cambridge, UK.

Jepma, C. J. 1995. Tropical Deforestation—A Socio-economic Approach. Earthscan Books, London, UK.

Juma, C. and Ojwang, J. 1996. In Land We Trust. Zed Books, London, UK.

Kemp, R.H. and Palmberg-Lerche, C. 1994. Conservation of Genetic Resources in Forest Ecosystems. *In* Readings in Sustainable Forest Management. FAO Forest Paper, Rome.

Lake, R. 1996. New and additional: Financial Resources for Biodiversity Conservation in Developing Countries, 1987–1994. Birdlife International, Cambridge, UK.

Mittermeir, R. and Bowles, I. 1993. The Global Environment Facility. Washington, D.C.

Myers, N. 1991. Deforestation Rates in Tropical Forests and their Climatic Implications. Friends of the Earth, London, UK.

Norton-Griffiths, M. 1996. The need for a conservation policy process in Kenya. Discussion Paper. UNEP, Nairobi.

Pearce, D. and Moran, D. 1994. The Economic Value of Biodiversity. Earthscan Books, London, UK.

Rodgers, W. A. 1993. The conservation of the forest resources of eastern Africa: past influences, present practices and future needs. *In*: Biogeography and Ecology of the Rain Forests of Eastern Africa. J. Lovett and S. Wasser, eds. CUP, Cambridge, UK.

Rodgers, W. A. 1995. Conservation of biodiversity: the approaches of the forest and wildlife sectors compared. *In*: Biodiversity Conservation in East Africa. Benun, L., ed. NMK, Nairobi.

Rosendal, G. K. 1995. The forest issue in post UNCED international negotiations: conflicting interests and a reconciliation. Biodiversity and Conservation 4: 91–107.

Secretariat, Convention on Biological Diversity. 1996a. Integrating Biodiversity into Agricultural Development. Paper 7, Third Meeting of Conference of Parties for CBD. Argentina, November 1996.

Secretariat, Convention on Biological Diversity. 1996b. Consideration of Agricultural Biological Diversity under the Convention on Biological Diversity. Paper 14, Third Meeting, Conference of Parties for CBD. Argentina, November 1996.

Sharma, N. P. 1993. Managing the World's Forests. Kendall/Hunt, Iowa.

Spellerberg, I. F. 1996. Conservation Biology. Longmans, Harlow.

Swanson, T. 1997. Global Action for Biodiversity. Earthscan, London, UK.

Tarasofsky, R. G. 1995. The International Forest Regime Legal and Policy Issues. IUCN, Gland.

UNEP. 1995. Global Biodiversity Assessment. UNEP, Nairobi.

WRI. 1990. World Resources 1990–1995. World Resources Institute, Washington, D.C.

Vandermeer, J. and Perfecto, I. 1997. The Agro-ecosystem: A Need for the Conservation Biologist's Lens. Editorial. Conservation Biology 11(3): 592–593.

WCST. 1996. Putting Environment on the Political Agenda-1996. Proceedings of a Workshop. July 1996. Wildlife Conservation Society of Tanzania, Dar es Salaam.

CONSERVING PLANT GENETIC DIVERSITY FOR SUSTAINABLE FOOD PRODUCTION IN SUB-SAHARAN AFRICA

N. Q. Ng
IITA, Genetic Resources Unit, Oyo Road
P. M. B. 5320, Ibadan, Nigeria Q.NG@CGNET.COM

SUMMARY

The importance of plant genetic resources to global food production and security has been recognized. The need for conservation of genetic diversity for use in farming was emphasized; this can be through direct introduction or through broadening of the genetic base of improved varieties or elite local germplasm by introgression of useful traits identified from genebank accessions. Significant global developments by the United Nations and CGIAR centers to promote the conservation and utilization of plant genetic resources were reviewed.

Strategies and methods for the conservation of plant genetic resources were presented. The important linkage between conservation and utilization was highlighted by the work done at the International Institute of Tropical Agriculture (IITA).

IITA has collected and assembled about 40,000 accessions of germplasm of many crop and plant species important to Africa. These include cowpea, rice, yams, cassava, maize, and plantain/banana. The germplasm accessions are conserved in *ex situ* genebanks at IITA. They are freely distributed to researchers on request to promote their utilization and the exchange of germplasm in a manner consistent with the Convention on Biological Diversity. The plant genetic resources at IITA have been extensively used by researchers worldwide and by IITA scientists. Genetic resources contributed very significantly to the success of IITA in developing many improved varieties. The improved varieties have been widely disseminated and tested in many countries in sub-Saharan Africa. Over the years, many improved varieties developed at IITA were selected and recommended by national research programs for adoption by farmers. This has had a great impact on food production in sub-Saharan Africa.

INTRODUCTION

The importance of plant genetic resources to global food security as well as to the security of the livelihood of millions of rural families was underlined at the first United Nations Conference on the Human Environment in Stockholm in 1972. Widespread loss of diversity at different levels of biological organization was recognized (TAC/FAO, 1972; Frankel, 1973). Thus, the conference called for concerted efforts to conserve and utilize naturally occurring genetic variability in all plants, ranging from microflora to giant trees, keeping in view the interests of both present and future generations.

In the same year (1972), the Technical Advisory Committee (TAC) of CGIAR, together with the Food and Agriculture Organization (FAO) of the United Nations sponsored an ad-hoc working group in Beltsville, Maryland, U.S.A. The matter of collection, evaluation, and conservation of plant genetic resources was discussed and a blueprint for genetic resources was recommended (TAC/FAO, 1972). In 1974, the CGIAR established the International Board of Plant Genetic Resources (IBPGR) in

collaboration with FAO at the headquarters of FAO in Rome, to coordinate a network for the conservation and promotion of the use of economic plants (IBPGR, 1981).

Several of the CGIAR centers were already in existence at the time (CIAT, CIMMYT, IITA, IRRI, and ICRISAT). These centers followed suit to establish or strengthen their genetic resources programs, to collect, conserve, utilize, and document the genetic resources of their mandated crops. Thus substantial work in collection, conservation, and utilization of genetic resources has been done by CGIAR centers during the past two decades. The IBPGR was later renamed the International Plant Genetic Resources Institute (IPGRI) and became an autonomous CGIAR center in 1992. Based on its past achievements, IPGRI further broadened its activities (IPGRI, 1993). Presently there are 11 CGIAR centers conserving plant genetic resources for food and agriculture. Together they hold more than half a million accessions of germplasm of major food crop, forage, and tree species.

The Convention on Biological Diversity was signed by over 150 heads of state at the United Nations Conference on Environment and Development held at Rio de Janeiro in June 1992. This marked a historic commitment by the nations of the world to conserve biological diversity and to ensure that biological resources are used sustainably and the benefits of such use are shared equitably. The framework agreement of the convention covered all genes, species, and ecosystems. It did not specify the species to be protected or sites for conservation. Individual nations were and are expected to develop national strategies, priorities, and plans for the implementation of the convention. National strategies have been made by many countries, but the level and completeness of the plans vary greatly.

In developing national strategies and priorities, particularly with reference to the conservation and utilization of plant genetic resources for food and agriculture (PGRFA), we should be aware of the past, present, or planned activities of national, regional, and international organizations around the world to get full benefits from the existing germplasm materials conserved in genebanks and avoid redundancy. Cooperation among national, regional, and international organizations could achieve greater efficiency. No nation can conserve all the plant biodiversity it needs. Nations are interdependent on plant genetic resources for food and agriculture.

In June 1996, the FAO held its Fourth Technical Conference on Plant Genetic Resources in Leipzig, Germany. For the conference, FAO prepared a report on the state of the world's genetic resources through a highly participatory process of inventory based on more than 150 countries' reports, CGIAR reports, and many regional meetings. It was a very elaborate report that gave a fairly accurate assessment of the state of the world's plant genetic resources for food and agriculture. It identified some strengths and inefficiencies in the current system for the conservation and utilization of PGRFA (FAO, 1996a). It included a very useful reference for national and international organizations to review and set their priorities and research strategies. The Global Plan of Action (GPA) grew out of the State of the World Report and was adopted at the Leipzig Conference, June 1996. The plan provides a framework and guide for actions to be taken at community, national, regional, and international levels for the conservation and sustainable use of plant genetic resources (FAO, 1996b). The GPA provides a set of recommendations for 20 interrelated activities grouped into four major themes:

- *in situ* conservation and development;
- *ex situ* conservation;

- use of plant genetic resources;
- institution and capacity building.

The GPA is the most ambitious program ever undertaken in the field of agricultural biodiversity. The Leipzig Declaration affirmed a government-level commitment to implementing the plan. Also, the World Food Summit, held in Rome in October 1996, recognized the plan, signifying the importance attached to its implementation. CGIAR welcomes the adoption of the plan. Full implementation requires a significant increase in the current levels of activities, with a corresponding increase in funds to be made available to finance implementation.

Following the Leipzig Conference, countries and individual institutions and organizations concerned with plant genetic resources have begun to use their own resources and existing capacity to implement the Global Plan of Action. As already mentioned, many CGIAR centers are involved in a very broad range of activities to conserve, characterize, and enhance PGRFA. The improved materials they have developed or selected are shared with national programs to improve food production and security, particularly in the developing countries. It is in this context that I wish to share some information with you at this meeting about the efforts being made by IITA to conserve and promote the use of plant genetic diversity and to contribute to the implementation of FAO GPA, in order to achieve the overall objectives of the Convention on Biological Diversity and Agenda 21 of the United Nations Conference on Environment and Development (1992).

THE AIMS OF IITA'S PLANT GENETIC RESOURCES ACTIVITIES

The main aims of IITA's plant genetic resources activities are (1) to improve the conservation and availability of plant genetic resources for utilization by national agricultural research systems (NARS) and other partners, particularly in Africa, and (2) to broaden the genetic base of IITA's mandated crops (cowpea, soybean, cassava, yams, *Musa*, and maize), thereby contributing in a sustainable manner to increased food production and to enhanced food security in sub-Saharan Africa.

IITA collects, conserves, documents, and distributes plant genetic resources of a wide range of crops and their wild relatives, including yams, cassava, plantain and banana, cowpea, wild Vigna, soybean, rice, and some underutilized and threatened crop species, such as Bambara groundnut and African yam bean, as well as some multipurpose trees and shrubs. Ongoing and future activities include (1) planned and targeted collection or introduction of germplasm to expand the *ex situ* collection, (2) development and application of the most appropriate conservation methods or strategies to conserve germplasm, (3) expanding the characterization and evaluation of germplasm, (4) establishment of core collections, (5) application of the technology of geographical information system (GIS) for germplasm research, and (6) enhanced availability of germplasm information.

In addition to conserving, documenting, and distributing plant genetic resources, IITA has a multidisciplinary team of scientists who conduct research to identify useful traits and assess genetic diversity through characterization and evaluation, and to document germplasm with descriptors (both conventional and molecular) to enhance greater and more efficient use of germplasm collections. They also investigate the nature of adaptation and genetic inheritance of important economic traits in IITA-mandated crops to help researchers to deploy the most appropriate breeding schemes for the further improvement of germplasm.

Another research activity of IITA is to broaden the genetic base of crop varieties through genetic enhancement by the introgression of useful agronomic traits identified from available germplasm, into elite germplasm or locally adapted varieties. This is a key element in achieving sustainable agricultural production and food security in sub-Saharan Africa. The distribution of both improved and local germplasm materials from IITA is backed up by the application of improved methods for pathogen detection and diagnosis to facilitate the safe exchange of germplasm to the targeted recipients.

COLLECTION OF PLANT GENETIC RESOURCES

The collection, conservation, and use of plant genetic resources for food and agriculture have been a major part of the activities of IITA since its inception. In response to the recommendation of TAC and the Stockholm Declaration, IITA established its Genetic Resources Unit (GRU) in 1975 to further collect, characterize, preserve, distribute, document, and study the genetic resources of food legumes, rice, and root and tuber crops in sub-Saharan Africa. In tune with its evolving mandate within the CGIAR system, IITA has, over the past 25 years, worked in close collaboration with other CGIAR centers, particularly the International Plant Genetic Resources Institute (IPGRI), the International Rice Research Institute (IRRI), the West African Rice Development Association (WARDA), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the International Center for Research in Agroforestry (ICRAF), the Centro International de Agricultura Tropical (CIAT), the Centro International de la Papa (CIP), International Livestock Research Institute (ILRI), and Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), as well as a few regional organizations such as the Centre de Cooperation Internationale en Recherche Agronomique pour le Developement (CIRAD) and the Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM), including some non-governmental organizations (NGOs).

Over time and in response to changing circumstances, the scope of IITA's conservation work has widened, and currently covers three different crop/plant groups:
1. Crop species for which IITA has a specific crop improvement mandate and their wild relatives, cowpea, yams, maize, cassava, plantain, and soybean. Rice and sweet potato are also maintained even though their improvement mandates have been transferred to WARDA and CIP, respectively.
2. African indigenous food legumes, although not within IITA's crop improvement mandate, are collected and preserved. These include Ñ Bambara groundnut, African yam bean, Kersting's groundnut, and other minor legumes important to Africa.
3. Cover crops, shrubs, and multipurpose tree species for use in farming systems or agroforestry research, such as *Mucuna pruriens*, *Gliricida sepium*, *Cajanus cajan*, *Leucaena* spp., *Acacia* spp. and many others.

The collection and conservation efforts have involved close cooperation with many African national programs and with IPGRI. Between 1975 and 1996, GRU made 65 plant exploration missions to more than 30 African countries and to Brazil, always in cooperation with national programs. It collected more than 20,000 samples of germplasm of many plant species and their wild relatives (Ng, 1982; Ng et al., 1987; IITA, 1993, 1998a). From time to time, IITA scientists from other programs also acquire or collect germplasm from national programs and collaborators worldwide for use in breeding programs or for specific research purposes. Presently, IITA conserves over 40,000 accessions of germplasm, mainly of the following important crops: cowpea

(14816), rice (12051), yams (2875), cassava (2100), soybean (2500), Bambara groundnut (2000), maize (1200), plantain/banana (350) and their wild relatives, as well as some trees and shrubs (Table 1). The collections represent the very large genetic variability of a wide range of important plant species, which will provide much-needed genetic materials for direct use in farming or in plant breeding to produce improved genotypes suitable for different agricultural systems in Africa.

Table 1. Germplasm collections conserved at IITA, December 1996.

Crop	Species	Number of accessions or samples
Major crop collections:		
Cowpea	*Vigna unguiculata*	14,816
Asian rice	*Oryza sativa*	9,451
West African rice	*O. glaberrima*	2,600
Yams	*Dioscorea* spp.	2,875
Bambara groundnut	*V. subterranea*	2,000
Cassava	*Manihot esculenta*	2,100
Soybean	*Glycine max*	2,500
Maize	*Zea mays*	1,200
Sweet Potato	*Ipomoea batatas*	217
Plantain and banana	*Musa* spp.	400*
Crop wild relatives:		
Vigna	*Vigna* (50 spp.)	1,161
Cowpea	*V. unguiculata*	490
Rice	*Oryza*	270
Cassava	*Manihot* (24 spp.)	110
Minor collections:		
Green gram	*V. radiata*	115
Trees and shrubs	Agroforestry species (over 50 spp.)	175
African yam bean	*Sphenostylis stenocarpa*	70
Winged bean	*Psophocarpus tetragonobus*	27
Pigeon pea	Cajanus cajan	25
Lablab bean	*Lablab purpureus*	42
Jack bean	*Canavalia ensiformis*	5
Sword bean	*Canavalia gladiata*	4
Mucuna	*Mucuna pruriens*	3
Rice bean	*V. umbellata*	6
Kersting's groundnut	*Macrotyloma geocarpum*	8
Total		40,670

* Maintained mainly at the Plantain/Banana Improvement Program at Onne.

CONSERVATION STRATEGIES

The two basic approaches to the conservation of plant genetic resources are *ex situ* and *in situ* methods; and these should be considered complementary. Each approach has various methods that can be applied for the conservation of genetic resources, depending on the nature of the germplasm, and availability of resources and facilities. Usually it requires integrated strategies, using a combination of the most cost-effective and appropriate methods, to conserve the entire gene pool of a concerned species.

In situ conservation is to conserve genetic materials in their natural ecosystem. It is commonly used for the conservation of forest genetic resources. Its application for the conservation of wild relatives of crop plants is gaining wide acceptance.

IITA is making use of a forest reserve with an area of more than 300 ha on site at IITA's headquarters in Ibadan for *in situ* conservation of the wild relatives of crop species and endangered plant species. Six wild yam species growing in this nature reserve are protected along with their ecosystem. Currently, populations of wild yams at several selected sites are being monitored and studied, with the objective of gaining knowledge on the population dynamics and the implications of *in situ* conservation.

Maintenance of landraces or traditional crop varieties on-farm and in home gardens has gained wide recognition as an effective way of conserving traditional crop varieties. For thousands of years, farmers selected and managed their plant genetic resources through gathering and domestication, continuous selection, and cultivation of cultivars most suitable to the surrounding environments in which the farmers forage and live. Farmers are creators and conservators of crop genetic resources, while at the same time they abandon what they do not need or cannot maintain because of social factors or biological constraints. It is impossible to rely on farmers to save all traditional cultivars they themselves have created or selected, unless there are some incentives and backup by institutions and governments. Management of germplasm on-farm for conservation purposes needs to be well designed. Educating farmers on the importance of maintaining genetic diversity and providing them with incentives could be an effective approach to promote on-farm conservation to complement *ex situ* conservation.

Currently, IITA does not have an on-farm conservation program. It has programs on farmer participatory breeding and evaluation of cowpea and yams by carrying out evaluation of breeding lines and elite local germplasm in farmers' fields. Farmers are involved in the selection and provide feedback on their needs to help IITA researchers to focus their research priorities.

Ex situ conservation maintains germplasm outside its original habitat, usually in facilities such as *in vitro* genebanks and field genebanks (nurseries, fields, and orchards). Botanical gardens are places where useful plant species and ornamental plants can be preserved *ex situ*.

Conserving seeds of orthodox species in genebanks is considered the most simple way of conserving PGRFA. The seeds are safe, and the method is cost-effective if managed properly. Genebank standards for the preservation of seeds were reviewed and recommended (IBPGR, 1982; Ng, 1991a; FAO/IPGRI, 1994).

IITA has two seed-storage units, conditioned at 5°C and about 25–30% relative humidity, for maintaining active seed collections for use in general distribution, multiplication, and evaluation, and other research. It also has two other units conditioned at -20°C and associated facilities for drying and packing seeds for long-term conservation (base collection) according to the preferred standard recommended by

the FAO/IBPGR Advisory Consultation on Genebank Standards (FAO/IPGRI, 1994). These have the capacity to accommodate and preserve more than 60,000 accessions of various crops for long-term conservation.

Field genebanks are useful for vegetatively propagated crops or species with seeds that are recalcitrant and difficult to store, including important food crops such as yams, cassava, potato, and sweet potato, and economically important industrial species such as rubber and cocoa. Field genebanks are easy to adopt but require big fields. Generally, plants are constantly under high pressure from pests and diseases. If these are annual crops, such as yams and potato, labor costs and management could pose problems especially when the collections are large. The existing collections of more than 5000 accessions of yams, cassava, and plantain/banana available at IITA are maintained in field genebanks. The collection of agroforestry species is maintained in an arboretum in Ibadan.

In vitro genebanks conserve materials in a nutrient medium, usually in test tubes or bottles, under reduced growth conditions. These have been very effective for the conservation of many plant species, including yams, cassava, plantain and banana, and potato (Ng, 1988 1991b;1992; Vuylsteke, 1989; Ng and Ng, 1991 1994) Presently, IITA maintains approximately 4000 accessions of yams, cassava, plantain/banana and sweet potato in *in vitro* genebanks (IITA, 1998a).

Cryopreservation stores organisms including seeds, dormant buds, meristems, pollens, and cells under very low temperatures, from 80°C below freezing to -196°C, in liquid nitrogen. This technique has been applied to conserve some tree species such as apple. The technique has been shown to be applicable for use in the conservation of cassava and potato and is also potentially useful for plantain, banana, and yams. Further research is still needed for its application in the conservation of a wide range of genotypes.

The DNA sequences in the genomes of germplasm accessions are the sources of the genes required in breeding programs. When identified and isolated by cloning, these genes may be used for the genetic transformation of crop plants. The preservation of these cloned DNAs as gene sources is comparable to the conservation of the genetic stock collection. IITA obtained several Bt genes from collaborators in advanced laboratories to try to use in cowpea for insect resistance. However, most of these cloned genes are protected by patents and are not freely available to anyone who wishes to exploit them.

Economic and technical reasons aside, it is unlikely that the conservation of DNA and the assembly of sequence databases will become alternatives to conventional germplasm conservation (Peacock, 1984; Flavell, 1991). To be of practical use, DNA requires the conservation of recipient organisms. Unlike a seed, embryo, or a vegetative propagule, a DNA sequence cannot as yet be used to regenerate a whole organism. Thus, the traditional genebank is essential to preserve the genes required for agricultural productivity. Conservation of cloned DNAs, or genes with known characteristics, can effectively complement traditional methods of germplasm conservation.

LINKAGE WITH USE

Germplasm is useful to scientists and plant breeders only when the material has been properly characterized and evaluated. In this way scientists are able to study the diversity of a species, to search for materials for direct introduction as cultivars, or provide genetic variability in breeding programs. At IITA, many of the accessions of

germplasm, are "grown out" every year for characterization (both botanical and molecular descriptors) and evaluation for biotic stresses and yield potentials.

At IITA, a computer database is kept for each of the following crop/plant species, with a range of information on passport data, characterization/evaluation data, and collaborator and exchange data:

Crop	Passport data	Characterization data
Cowpea	11	47
Rice	12	40
Bambara groundnut	7	46
Soybean	4	6
Yams	14	60
Cassava	8	46
Wild Vigna	10	72

The status of characterization and evaluation of IITA's germplasm collections varies from crop to crop. Some are quite complete and comprehensive. For example cowpea, with over 11,000 accessions and rice, with about 10,000 accessions, have been characterized. IITA will continue to characterize and evaluate germplasm, with emphasis on its mandated crops.

Most of the information from IITA's databases has been replicated and placed in the public domain through the World Wide Web site (http://www.cgiar.org/singer) of the Systemwide Information Network for Genetic Resources (SINGER). Those who have access to INTERNET facilities can have direct access to the database. A CD-ROM version of the SINGER databases comprising data from 10 CGIAR centers, including IITA, is also available (SGRP, 1997).

The available plant genetic resources in IITA's genebanks and elsewhere have contributed to IITA's success in improving cowpea, rice, maize, cassava, plantain, soybean, and yams for use by farmers. This has been achieved through the selection of elite local germplasm and through genetic enhancement to broaden the genetic base of improved varieties by the introgression of useful agronomic traits identified from the available germplasm into elite breeding lines or locally adapted varieties. Improved varieties include cassava clones resistant to cassava mosaic disease and bacterial blight, maize varieties resistant to the maize streak virus, cowpea that are extra-early maturing and resistant to multiple diseases, soybean varieties with good seed storability that have promiscuous nodulation as well as resistance to bacterial pustule and lodging, and plantain hybrids with resistance to black sigatoka. Other examples that could be cited are high-yielding, long-grain rice with resistance to *Diopsis* stem borer and rice yellow mottle virus, and yam varieties with resistance to viral diseases. The improved germplasm developed at IITA is freely distributed to NARS, through research networks such as the East Africa Root Crops Research Network (EARRNET), the Southern Africa Root Crops Research Network (SARRNET), Cassava International Trials of West and Central Africa, Cowpea International Trials and Regional Uniform Maize Variety Trials in West and Central Africa, and to interested researchers on request. Thousands of both improved varieties/breeding lines and selected elite local germplasm accessions are distributed from IITA to researchers in many countries in Africa (Tables 2–4).

Table 2. IITA's improved germplasm of cowpea, maize, and soybean distributed to NARS in Africa during 1996 (IITA, 1998a).

Crop	No. of countries	No. of sets
Cowpea	18	101
Maize	16	299
Soybean	14	36

Table 3. Distribution of virus-tested *in vitro* plantlets and minitubers of white yam from IITA to African countries, 1993–1996 (IITA, 1998c).

	Plantlets		Minitubers	
Year	No. of countries	No. of plants	No. of countries	No. of tubers
1993	14	400	7	1,400
1994	13	1,772	9	1,100
1995	14	4,599	5	3,417
1996	9	3,689	7	5,500
Total	50	10,460	28	11,517

Table 4. Distribution of virus-tested cassava *in vitro* plantlets from IITA to African countries, 1993–1996 (Bonierbale et al., 1998; IITA, 1998b).

	No. of genotypes			
Year	Improved	Local	No. of countries	No. of plantlets
1993	104	2	18	3,007
1994	128	2	18	2,385
1995	235	11	24	8,291
1996**	284	19	20	11,271
Total	751	34	80	24,954

** In addition, another 18,090 plantlets comprising 16 genotypes were distributed to Angola for the World Vision Project (NGO).

Many improved crop varieties/breeding lines developed at IITA (Table 5) have been selected and released for adoption by farmers over the past two decades. These lines have had a great impact on increasing food production in many African countries.

Table 5. IITA's improved germplasm released by national programs in different African countries (IITA, 1994, 1998b; Singh et al., 1997).

Country	Crop	Breeding line/variety
Angola	Cowpea	TVx 3236
Benin Republic	Cowpea	VITA-4, VITA-5, IT82E-32
	Cassava	TMS 30572, TMS 30572A, TMS 4(2)1425

Table 5 (continued). IITA's improved germplasm released by national programs in different African countries.

Country	Crop	Breeding line/variety
Benin Rep.	Maize	TZB-SR, 43-SR, DMR-ESR-W, 30-SR
Botswana	Cowpea	ER-7, TVx 3236
Burkina Faso	Cowpea	TVx 3236, VITA-7 (KN-1)
	Maize	EV 8422-SR, EV 8430-SR, EV 8431-SR
Burundi	Cassava	TMS 40160/3, TMS 40160/1
Cameroon	Cowpea	IT81D-985, IT81D-994, TVx 3236
	Maize	TZB-SR, TZPB-SR, TZB derivation, DMR-ESR-Y, Kasai-SR, Suwan 1-SR, 8321-18, 8556-6
	Cassava	TMS 8034, TMS 8017, TMS 8061, TMS 82516
Central Africa Republic	Cowpea	VITA-1, VITA-4, VITA-5
Chad	Cowpea	IT81D-994
Congo	Maize	8644-27
Ethiopia	Maize	Gusau 81 TZB, Gusau TZB-SR
Gabon	Cassava	CIAM 76-6, CIAM 76-7, CIAM 76-13, CIAM 76-33, TMS 42025, TMS 30555, TMS 30337, TMS 40160, TMS 4(2)1425
Gambia	Cassava	TMS 60142
Ghana	Cowpea	IT82E-16, IT83S-728-13, IT83S-818, TVx 1843-IC, TVx 2724-0IF
	Maize	49-SR, Pool 16-SR, 43-SR, QPM Pop63-SR
	Cassava	TMS 30572, TMS 5039, TMS 4(2)1425
	Soybean	TGx 297-192C, TGx 306-036C, TGx 888-49C, TGx 536-02D, TGx 297-10F, TGx 813-6D
Guinea	Cowpea	IT85F-867-5
	Cassava	TMS 30572
Guinea Bissau	Cassava	TMS 4(2)1425, TMS 60142
Liberia	Cowpea	IT82D-889, TVx 3236, VITA-5, VITA-4, VITA-7
	Cassava	CARICASS 1, CARICASS 2, CARICASS 3
Mozambique	Cowpea	IT82E-18
	Cassava	TMS 30001, TMS 30395, TMS 42025
	Maize	Matuba, SEMOC-1 (DMR-ESR-W)

Table 5 (continued). IITA's improved germplasm released by national programs in different African countries.

Country	Crop	Breeding line/variety
Niger	Cassava	TMS 4(2)1425
Nigeria	Cowpea	IT84S-2246, TVx 3236, IT82E-60, IT81D-994, IT86D-719, IT86D-721, IT82D-716, IT84E-124, IT84E-1-108, IT90K-76
	Cassava	TMS 50395, TMS 30572, TMS 30001 TMS 4(2)1425, TMS 30555, TMS 91934, TMS 82/00058, TMS 81/00110, TMS 81/00661, TMS 90257, TMS 84537
	Soybean	TGx 849-313D, TGx 1019-2EN, TGx 1019-2EB, TGx 1448-2E, TGx 536-02D, TGx 306-036C
	Maize	
	Open-Pollinated	TZPB, 096EP6, TZMSR-W, TZSR-Y, TZSR-W, TZEYR-W, TZESR-Y, DMR-LSR-W, DMR-LSR-Y, DMR-ESR-W, DMR-ESR-Y, TZB-SR, TZPB-SR, EV 49-SR, POOL 16-SR, Suwan 1-SR, EV43-SR
	Hybrid	8321-18, 8321-21, 8322-3, 8322-13, 8329-15, 8341-5, 8425-8, 8428-19, 8434-11, 8505-2, 8505-3, 8505-4, 8505-5, 8505-13, 8644-27, 8644-31, 8644-32, 8516-12, 8535-23, 8556-6
	Cooking banana	Cardaba
Rwanda	Cassava	TMS 30572, Gakiza (UYT bulk 1977), Karana (PYT bulk 1977)
So-Tom	Maize	TZSR-Y-1, TZSR-W-1
Senegal	Cowpea	TVx 3236
Sierra Leone	Cowpea	TVx 1999-01E
	Maize	TZSR-Y-1, EV 26-SR
	Cassava	ROCASS 1, ROCASS 2, ROCASS 3, NUCASS 1, NUCASS 2, NUCASS 3, 80/40
Somalia	Cowpea	TVx 1502
Sudan	Maize	DMR-ESR-W, DMR-LSR-W, Gusau TZB
Swaziland	Cowpea	IT82E-18, IT82E-32, IT82E-71
Tanzania	Cowpea	TK-1, TK-5, IT82D-889

Table 5. (continued). IITA's improved germplasm released by national programs in different African countries.

Country	Crop	Breeding line/variety
Togo	Cowpea	VITA-5, TVx 3236
	Maize	49-SR, 8322-13 STR
	Cassava	TMS 4(2)1425, TMS 30572
Uganda	Cowpea	TVx 3236, IT82E-60
	Cassava	TMS 30572, TMS 60142, TMS 30337
	Maize	Acr 83 TZMSR-W, 8535-23, 8556-6
Zaire	Cowpea	IT82E-18, IT82E-32
	Maize	83TZMSR-W, IK 83 TZSR-Y-1
	Soybean	TGx 814-76D, TGx 849-294D
	Cassava	Kinuani, F100, TMS40230/3
Zambia	Cowpea	TVx 456-01F, TVx 309-1G, IT82D-889
	Cassava	LUC 133

In addition to improved germplasm, numerous sources of resistance to pests and diseases have been identified from the existing germplasm collections maintained at IITA and they are available on request to national research programs (Bonierbale et al., 1998; IITA, 1998a; Ng and Padulosi, 1991; Ng et al., 1994; Ng and Singh, 1998). Between 1978 and 1996, over 50,000 samples of various crop species and their wild relatives were distributed by GRU to 80 countries worldwide (Table 6). The figures showed that the materials conserved at IITA are well used.

Table 6. Distribution of germplasm samples from IITA's Genetic Resources Unit to non-IITA researchers in more than 80 countries worldwide, 1978–1996* (IITA, 1994, 1998b; Singh et al., 1997).

Region	Cowpea	Rice	Bambara groundnut	Wild Vigna	Soybean	Winged bean	Others	Total
Africa	11,844	8,532	1063	675	1,019	645	1,475	21,383
Asia	4,741	9,502	131	89	19	151	1,233	15,866
Europe	1,995	1,922	109	568	19	181	963	5,765
Americas	3,247	1,345	309	117	7	191	1,144	6,361
Total	21,827	21,301	1,612	1,449	1,064	1,168	5,174	53,601

* excluding samples used by IITA's researchers or improved germplasm materials distributed by IITA's plant breeders to national programs.

CONCLUSIONS

Plant genetic resources for food and agriculture need to be collected for conservation in *ex situ* genebanks for utilization. The genebank collections need to be protected, sustained, and expanded where necessary. Whenever possible, *ex situ*

conservation should be complemented by *in situ* methods. *Ex situ* and *in situ* methods of conservation are complementary. Conservation of plant genetic resources should be linked to use. Germplasm is useful to scientists and breeders only when the materials have been characterized and evaluated.

Broadening the genetic base of crop varieties through direct introduction or through genetic enhancement requires a very broad range of variability of genetic materials to be available for use by breeders and agronomists. The collections of germplasm available at IITA have been extensively used by researchers worldwide and have contributed significantly to IITA's success in improving cowpea, rice, maize, cassava, plantain, soybean, and yams for use by farmers for sustainable food production in many countries in sub-Saharan Africa.

REFERENCES

Bonierbale, M., Guevara, C., Dixon, A. G. O., Ng, N. Q., Asiedu, R., and Ng, S. Y. C. 1998 (in press). Cassava in biodiversity in trust, In: Conservation and Use of Plant Genetic Resources in CGIAR centers. Ó. D. Fuccillo, P. Stapleton and L. Sears, eds. Cambridge Univ. Press, Cambridge, UK.

FAO. 1996a. Report on the State of the World's Plant Genetic Resources for Food and Agriculture. Prepared for the International Technical Conference on Plant Genetic Resources Leipzig, Germany, June 17–23.

FAO. 1996b. The Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture. Prepared for the International Technical Conference on Plant Genetic Resources, Leipzig, Germany, June 17–23.

FAO/IPGRI. 1994. FAO/IPGRI Genebank Standards. Food and Agriculture Organization of the United Nations, Rome, and International Plant Genetic Resources Institute, Rome.

Flavell, R. B. 1991. Molecular Biology and Genetic Conservation Programs. Biological Journal of the London Society 43: 73–80.

Frankel, O. H. 1973. Survey of Crop Genetic Resources in Their Centers of Diversity. First Report. FAO/IBP, Rome, Italy.

IBPGR. 1981. Crop Genetic Resources. International Board for Plant Genetic Resources, Rome, Italy.

IBPGR. 1982. Design of Seed Storage Facilities for Genetic Conservation. Revised 1985 and 1990. International Board for Plant Genetic Resources, Rome, Italy.

IITA. 1993. Genetic Resources Unit Status Report. Crop Improvement Division. International Institute of Tropical Agriculture, Ibadan, Nigeria.

IITA. 1994. Annual Report 1993. International Institute of Tropical Agriculture, Ibadan, Nigeria.

IITA. 1998a (in press). Annual Report 1996: Conservation and Genetic Enhancement of Plant Biodiversity. International Institute of Tropical Agriculture, Ibadan, Nigeria.

IITA. 1998b (in press). Annual Report 1996: Cassava Productivity in the Lowland and Midaltitude Agroecologies of sub-Saharan Africa. International Institute of Tropical Agriculture, Ibadan, Nigeria.

IITA. 1998c (in press). Annual Report 1996: Improvement of Yam-based Systems. International Institute of Tropical Agriculture, Ibadan, Nigeria.

IPGRI. 1993. Diversity for Development. The Strategy of the International Plant Genetic Resources Institute. International Plant Genetic Resources Institute, Rome, Italy.

Ng, N. Q. 1982. Genetic Resources Program of IITA. Plant Genetic Resources Newsletter 49: 26–31.

Ng, N. Q. 1991a. Long-term seed storage, in: Crop Genetic Resources of Africa, Vol. I. N. Q. Ng, P. Perrino, F. Attere and H. Zedan, eds. International Institute of Tropical Agriculture, Ibadan/International Board for Plant Genetic Resources, Rome/United Nations Environment Program, Nairobi, Kenya.

Ng, N. Q. and Ng, S. Y. C. 1994. Approaches for the conservation of yam. *In*: Root Crops for Food Security in Africa. M. O. Akoroda, ed., International Society for Tropical Roots Crops, African Branch, CTA, IITA, Ibadan, Nigeria.

Ng, N. Q., and Padulosi, S. 1991. Cowpea genepool distribution and crop improvement. *In*: Crop Genetic Resources of Africa Vol. II. N. Q. Ng, P. Perrino, F. Attere and H. Zedan, eds., International Institute of Tropical Agriculture, Ibadan/International Board for Plant Genetic Resources, Rome/United Nations Environment Program, Nairobi, Kenya.

Ng, N. Q., Asiedu, R., and Ng, S. Y. C. 1994. Cassava genetic resources program at the International Institute of Tropical Agriculture, Ibadan. *In*: Report of the First Meeting of the International Network for Cassava Genetic Resources. CIAT, Cali, Colombia, August 18–23. International Crop Network Series No. 10, International Plant Genetic Resources Institute, Rome, Italy.

Ng, N. Q., Goli, A. E., Padulosi, S. and Osunmakinwa, A. A. 1987. Exploration for land races and wild species of food crops. IITA Research Briefs 8(4): 5–7.

Ng, S. Y. C. 1988. *In vitro* tuberization in white yam (*Dioscorea rotundata* Poir). Plant Cell Tissue and Organ Culture 14: 121–128.

Ng, S. Y. C. 1991b. *In vitro* conservation and distribution of root and tuber crops germplasm. *In*: Crop Genetic Resources of Africa, Vol. II. N. Q. Ng, P. Perrino, F. Attere and H. Zedan, eds. International Institute of Tropical Agriculture, Ibadan/International Board for Plant Genetic Resources, Rome/United Nations Environment Program, Nairobi, Kenya.

Ng, S. Y. C. 1992. Micropropagation of white yam (*Dioscorea rotundata* Poir). *In*: Biotechnology in Agriculture and Forestry, Vol. 19. Y. P. S. Bajaj, ed., High-Tech and Micropropagation III, Springer-Verlag, Berlin, Heidelberg.

Ng, S. Y. C and Ng, N. Q. 1991. Reduced growth storage of germplasm. *In*: *In vitro* Methods for Conservation of Plant Genetic Resources. J. H. Dodds, ed. Chapman and Hall, London, UK.

Ng, N. Q. and Singh, B. B. 1998 (in press). Cowpea in Biodiversity in Trust. *In*: Conservation and Use of Plant Genetic Resources in CGIAR Centers. D. Fuccillo, P. Stapleton and L. Sears, eds., Cambridge Univ. Press, Cambridge, UK.

Peacock, W. J. 1984. The impact of molecular biology on genetic resources. *In*: Crop Genetic Resources: Conservation and Evaluation. J. H. W. Holden and J. T. Williams, eds., George Allen and Unwin, London, UK.

SGRP. 1997. System-wide Information Network for Genetic Resources (SINGER) CD-Rom set. Version 1.0. CGIAR System-wide Genetic Resources Program. IPGRI. Rome, Italy.

Singh, B. B., Chambliss, O. L., and Sharma, B. 1997. Recent advances in cowpea breeding. *In*: Advances in Cowpea Research, B. B. Singh, D. R. Mohan Raj, K. E. Dashiell and L. E. N. Jackai, eds. Co-publication of International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Science (JIRCAS). IITA, Ibadan, Nigeria.

TAC/FAO. 1972. The collection, evaluation and conservation of plant genetic resources. Report of the TAC ad hoc Working Group, Beltsville. TAC Secretariat/FAO, Rome, Italy.

United Nations Conference on Environment and Development. 1992. United Nations Conference on Environment and Development, Agenda 21. Geneva, Switzerland.

Vuylsteke, D. R. 1989. Shoot-tip Culture for the Propagation, Conservation and Exchange of Musa Germplasm. Practical Manuals for Handling Crop Germplasm *In vitro* 2. IBPGR, Rome, Italy.

THE CONSERVATION AND UTILIZATION OF PLANT RESOURCES IN EAST AFRICA: ISSUES IN FOREST ECOSYSTEM MANAGEMENT

James Legilisho-Kiyiapi
Department of Forestry, Moi University
P.O. Box 1125, Eldoret, Kenya

SUMMARY

East Africa (Kenya, Uganda, and Tanzania) is endowed with a variety of sites, rich in plant diversity, which are under considerable and varied stresses arising from a multiplicity of factors: historical, ecological, technical, and socioeconomic. Conservation of plant resources in the region is therefore influenced by these general factors, as well as complex institutional interactions. The extent of plant genetic resource erosion in the region is outlined and underlying causes examined, focusing on closed forests. Specifically, the paper seeks to (1) highlight key forest ecosystems of biodiversity significance ("hot spots") and (2) analyze key issues (constraints) in forest conservation and management from a regional perspective and explore avenues for intervention. The paper seeks to identify areas of commonality toward a more focused conservation agenda. The role of rural communities is critically examined and constraints to new themes in collaborative or participatory management addressed.

INTRODUCTION

The last two decades have seen significant shifts in forest management paradigms. Not only has the rationality of state-controlled, highly centralized management of forests been questioned, but indeed, the view that forestry as a profession has largely focused on a singular objective, production of timber. Silvicultural systems, e.g., those tried in tropical moist forests were primarily designed to manipulate forest ecosystems in favor of the so-called desirable species (meaning high value hardwood species) at the expense of the "undesirable" weed species. This narrow perspective has been challenged (at least in theory) and a broader perspective engendered in which the forest is not seen merely as a stand of trees but rather as a complex biological and physical system in which there is an enormous variety of interaction and interdependency. This thinking is not exclusively confined to the biological domain, but has placed forestry at the center of socioeconomic and political debate locally, nationally, and globally. A new perception in the paradigm, one that is gaining currency, embraces a wider definition of a forest ecosystem, that in any particular locality, the forest and the people who depend upon it should be considered as a single ecosystem. Until very recently, the holistic nature of forest ecosystem dynamics, in particular the functional linkages between people and forests, has not received adequate recognition. Forest ecosystem management allows the use of recently developed systems to generate and test holistic models based on ecosystem dynamics that will focus on key interactive biophysical and socioeconomic elements of forest performance.

Despite the unprecedented global interest and current high level discourse on forest issues, world forests continue to decline at an alarming rate. It is something of a paradox that in spite of a massive infusion of capital and human resources leading to a

battery of conservation initiatives, we are not seeing a corresponding impact in reversing deforestation trends. This is troubling because a large fraction of the earth's biological diversity lives in forests, or depends on forests, especially tropical forests. Some estimate (Lovejoy, 1988) that 90% of the world species lived in tropical rain forests despite occupying only 7% of the land area. Known manifestations of the loss of biodiversity are habitat loss and fragmentation, over harvesting, introduced species, chemical pollution, global climatic changes, and agricultural and forest industries. The threat to the great wealth of plant and animal germplasm of tropical forest ecosystems underscores the urgency of developing effective conservation strategies. A significant outcome of the conservation debate has been the realization that forest conservation issues go beyond biology. They encompass rural sociology and anthropology, policies and land use legislation, economics and politics. East Africa as a region represents a wide diversity of forest sites as well as socioeconomic contexts. This paper attempts to provide an overview analysis of conservation issues, with examples drawn from the region. The paper does not attempt a detailed review of country's conservation status; rather it seeks points of commonality toward pointing out areas that should be the focus of future conservation strategies.

FOREST RESOURCES

In absence of detailed inventory data, the precise acreage of natural forest cover in East Africa is hard to determine. In Kenya, indigenous forest cover is estimated at about 1.1 m ha comprising of coastal forest (82,500 ha), dry forest (211,000 ha), montane forest (748,500 ha), and western rainforest (49,000 ha) (Wass, 1995). Plantations are estimated at 160,000 ha, but due to high levels of understocking and backlog in planting, the area under tree cover is probably much smaller. Apart from the invasion of secondary species, usually in the understory in very low stocking plantations, forest plantations generally represent species-poor ecosystems. The total closed forest area in Tanzania has been estimated between 1.44–1.6 m ha. In Uganda, closed forest is estimated at 0.7–1.5 m ha. The poor quality of data available means that there is a variation in figures reported depending on the source consulted. These figures do not mean much because, in the first place, data are based on crude assessment of major forest blocks (usually those under gazettement) and do not account for all the forested areas including pockets of closed canopy forests dispersed within extensive dry woodlands. Some potentially useful data may be available, but are locked up in unpublished reports that are not readily accessible. Data constraints have greatly hampered our ability to comprehend the magnitude of loss, and to formulate sustainable alternatives to resource depletion. Forests in the Eastern Africa region show a considerable degree of variability in structure and species composition due to the variety of relief and climatic conditions and their evolutionary histories. The volume *The Biogeography and Ecology of the Rain Forests of Eastern Africa*, edited by Lovett and Wasser, provides a comprehensive treatment of East African flora with special emphasis on biodiversity "hot spots." Wasser and Lovett (1993) divide Eastern African forests into three geographical types.

- The Eastern Arc mountain forests formed on ancient crystalline mountains. Due to old age, and a high degree of fragmentation (isolation), these forests have a remarkable level of species diversity and endemism. They estimate the level of endemism at 25–30% of 2000 East Africa moist forest plants.

- Forests of more recent origin on volcanic mountains—Mt. Meru, Kilimanjaro, Mt. Kenya, and Mt. Elgon forests.
- Coastal forests overlying sedimentary rocks.

There are also remnants of tropical rain forests (e.g., Kakamega forest in Kenya), Albertine rift forests in western Uganda forming fringes of the rich central Africa rain forest, and swamp forest ecosystems around Lake Victoria. Compared with the more continuously distributed Western and Central African forests, Eastern African forests are highly fragmented, largely due to human-induced disturbances. Although interest has focused mainly on the closed-canopy moist forests, dry woodlands contain plant resources important from both a conservation standpoint as well as from socioeconomic and cultural perspectives. For example, the dry mountain forests on the Kenya-Uganda border (Loima hill forests in Kenya and Moroto in Uganda) represent a unique set of human-forest resource interactions. Plant germplasm has been conserved in these dry mountain forests through strong traditional conservation mechanisms of pastoral communities. The forests are increasingly coming under immense pressure from external forces, which not only seek to exploit the resource but would inevitably lead to breakdown of the traditional systems through disruption of the pastoral ecology, thus placing the conservation of the forests in greater jeopardy.

FOREST LOSS, MANAGEMENT PROBLEMS, AND CONSERVATION NEEDS

The major problem in East Africa is that forests are under considerable pressure manifested by reduced forest area, over exploitation, and attendant degradation. According to Japman (1995), FAO estimated rate of forest loss for Kenya (0.6%), Uganda (1.0%), and Tanzania (1.2%). The Kenya Forestry Master Plan (MENR, 1994) estimates the country's annual forest cover decreases at a rate of 5000 ha per year. Deforestation worldwide has been attributed to direct causes (agricultural expansion, overgrazing, fuel wood gathering, commercial logging, infrastructure and industrial development), underlying causes (market and policy failures, population growth, and rural poverty), and economic imperatives (Rowe et al., 1992). Rodgers (1993) gives a detailed multi-perspective analysis of forestry development in East Africa—historical as well as the range of technical and institutional issues. The continued loss and degradation of forest ecosystems in East Africa can be analyzed from a broad spectrum of perspectives hinging on the above-mentioned direct and underlying causes. These factors interact in a complex and dynamic manner at the forest level as well as a national and regional level, and in some cases with significant global influence. In all three East African countries, these interactions can be examined from several perspectives.

Forest Land has Other Competing Land use Alternatives

High population growth rates in the region places a premium on forest land. Short-term economic gains accruing from land cultivation and development often outweigh long-term conservation objectives. Unless alternatives are developed that encourage and give incentives to rural farmers to intensify their production systems, and benefit directly from forest conservation and management, this will likely continue to cause the loss of plant germplasm. The solution to the problem will involve: land-use policies at least at the national level; the question of security of land and resource tenure for rural communities; the issue of forest conservation, management benefits, and the problem of equity. These relate directly to the need for integrated land-use planning,

and natural resource management. Such land-use planning must be backed by effective policy instruments. It would involve, for example, multiple-level planning and sectoral integration of relevant government agencies. The concept of zonation becomes applicable. At the forest level fully protected zones for biodiversity conservation are delineated; forest zones are managed for production and/or protection; and zones best suited for sustainable agricultural development, including agroforestry and livestock development, are also mapped out.

National parks, which are mainly found in dry savanna woodlands forest reserves, are usually in high potential agricultural areas and limited exploitation is allowed. Consequently, they are more vulnerable to human-induced degradation. In general, Protected Areas (PAs) are not influenced and controlled in a tight within-boundary system, but within a broad resource—determined continuum that goes far beyond the forest boundaries. Sustainable utilization of plant resources outside protected areas has a positive influence on conservation in protected areas. Therefore conservation strategies must not focus solely on the sharply delimited PAs, but consider them within a hierarchy of protection status—utilization level zones. The issue of conserving forest resources within an integrated land use framework poses great challenges because it involves fundamental institutional changes. New policy and legislative reforms in the region may bring about a significant shift in this direction.

Forest Exploitation

This is the most complex interaction and one that is highly site-specific. Forest cover is reduced because land is needed for other purposes (e.g., agriculture), and because demand for forest products far outstrips supply.

Subsistence-driven Exploitation

Rural communities exploit forest resources in their immediate vicinity for provision of timber and a wide range of non-timber forest products. Although such exploitation is largely for domestic use, some products are exploited by local people for markets over much larger distances (e.g., dug-out canoes, honey, medicines, fruits, and alcohol) (Rodgers, 1993). What needs to be stressed here is that a great number of communities in East Africa live away from forests and cannot be thought of as "indigenous peoples" living in harmony with nature. Several of the assumptions made in conservation literature on sustainability, extraction, and economic value of forest products used by local people remain untested (Godoy and Bawa, 1993). Rural communities are extremely heterogeneous with diverse interests hinging on socioeconomic imperatives, cultural and political affiliations. At the local level, people make decisions affecting their daily lives based on their own special circumstances or influences that are sometimes outside their control. This means that the impact of rural communities on forest ecosystems should be seen within the context of diversity of interests. There is often the perception that local people exploit forests for provision of fuel wood, thatching materials, building poles, etc., primarily for subsistence use; such a view must be firmly rejected as it is not indicative of realities on the ground. For example, in the well-known forests of the East Usambara mountains in Tanzania, likened in biodiversity terms to the Galapagos Islands in the Pacific (Rodgers and Homewood, 1982), illegal extraction of timber (pitsawing) to service timber markets in Tanga town continues despite a series of conservation interventions (e.g., by the World Conservation Union, IUCN (1996) since 1980s and European Commission support

since 1988). The remnants of the Taita hill forests in Kenya (also part of Eastern Arc Mountain forests) provide another example where diverse community interests exert various impacts on the forests. Local people exploit these forests because of lack of alternatives (e.g., scarcity of fuel wood sources as a result of previous clearance of natural forests for agriculture and settlement exacerbated by high population pressure) but, in addition, local elites dispersed within the community provide a ready market for prime timbers to build their homes. There are other timber markets in urban centers as far away as the coastal town of Mombasa. These established markets aggravate illegal exploitation of timber species often executed by locals. Another case in point is a block of community forests adjacent to the Maasai Mara National Reserve (in the Transmara district in Kenya). The Maasai community traditionally practiced pastoralism—a land-use system that was compatible with conservation. While this traditional land-use system is still central to a majority of the Maasai people, individual initiatives to engage in large-scale agricultural production and to increase in subsistence cultivation (which in general leads to fragmentation of the forest ecosystems and attendant incompatibility with conservation objectives) are increasingly becoming common. Therefore, conservation strategies should recognize this diversity of interests and seek to address the issue of unsustainable exploitation, which at the moment is very difficult to determine due to lack of data. As substantial sums of money would be required to carry out comprehensive national inventories, forest specific inventories to generate baseline date on resource exploitation dynamics provide a realistic way to move forward.

Commercial logging

The three East African nations (Kenya, Uganda, and Tanzania) are sources of a variety of hardwoods as well as softwoods that are highly valued in furniture, flooring, construction, and joinery industries. The high demand for timber will continue to exert enormous pressure on existing forests. Examples of indigenous tree species exploited in the region include *Olea capensis, Khaya ivorensis, Vitex kiniensis, Ocotea usambarensis*, and *Milicia excelsa*. Large quantities of African mahogany (common name for species occurring in the genera *Entandrophragma* and *Khaya*) are exported from Zaire and Uganda largely to markets within the region. The carving industry has put a strain on species such as *Dalbergia melanoxylon,* which is in high demand due to its beautiful purplish black heartwood and durability. Government forestry departments (divisions) regulate timber harvests in forest reserves. This regulation is, in most cases, very ineffective because of strong political influences, powerful timber industry lobbyists, and non-existent or extremely inefficient policing mechanisms against illegal extractions. Moreover, the relevant legislations (currently being reviewed) impose penalties on illegal timber extractors that have no bearing on the value of timber removed and therefore are not a deterrent at all.

The demand for some of the species is clearly far beyond the level of supply. In some cases this forces governments to impose stricter controls on or even ban species use including *Ocotea usamberensis, Olea capensis, Juniperus procera* (Kenya), and *Milicia excelsa* in Tanzania. The lucrative international market for the bark of *Prunus africana* (pygeum) is currently driving the species use to unsustainable levels in Kenya. Furthermore, methods of logging in natural forest have negative impacts on ecosystem processes and functions and, thus, contribute to erosion of plant germplasm. The large sums of money involved in the timber trade, in relation to the meager salaries paid to foresters who sanction the licensing, and multi-stakeholder involvement (timber

industry, government, small-scale saw millers, pitsawyers) complicates control mechanisms when it comes to timber trade at macro and micro levels. Forest plantations augment in a substantial way timber supply from natural forests; in fact, this was the whole idea of compensatory forestry in the tropics. Fast-growing pine and eucalyptus plantations could be established in areas where natural forest cover had already been removed. Such plantations would then help to relieve pressure from the natural forests.

Far more important from a regional perspective is cross-border timber and non-timber forest product trade. Following the onset of increased East Africa collaboration, this is likely to be a serious problem. In a recent senior forest officers' meeting held in Arusha, Tanzania (December 1995), participants cited illegal crossborder timber trade as being one of the issues that need addressing. For example, large quantities of timber from Uganda find their way into markets in the neighboring countries, exerting tremendous pressure on the forest resources of that country. The Kenya policy encourages traders to bring timber into the country without any import permit. The degradation of the gazetted Namanga hill forest on the Kenya-Tanzania border has accelerated in recent years due to cross-border transfer of materials. The timber is illegally exploited in the forest (which is on the Kenyan side of the border), taken to Tanzania, and then brought back into Kenya as imported timber! The forest is one of the focal points in a Global Environment Facility (GEF)-funded regional biodiversity project that is presently being developed for the region. From the foregoing analysis, conservation strategies must not only try to improve management (as will be discussed in the following section) but should also address:

- The issue of regulations on trade both within and across country borders. Control mechanisms will need to be put in place to curb illegal cross-border timber trade, e.g., by use of timber certification. This can be achieved by reviving and rejuvenating the former East African Timber Advisory Board.
- Intensive management of exotic forest plantation as a realistic option for meeting the country's high demands for round wood. There is also a potential of establishing many indigenous species in large-scale plantations. Domestication offers another range of possibilities for endangered timber species. It has been argued that if useful desirable varieties of a species are developed and cultivated *ex situ*, this would help to conserve the species genetic variability *in situ*. Simons (1996) suggests that such a strategy would ensure that raw germplasm can be protected in the natural ecosystems while the germplasm of greatest utility value can be conserved and promoted through the cultivation and domestication of trees on farms. This seems to be the research thrust among ICRAF scientists.

Forest Management

Forest management involves a broad spectrum of activities involving the forest resource. This is perhaps the single most problematic and controversial aspect of forestry. The range of issues involved is wide, and cannot be exhaustively analyzed here. There are, however, several aspects worth underscoring within the East African region. Forest departments (divisions) in all three countries are characterized by inadequate capacity not only in ensuring effective forest policing, but in implementing technical aspects of forest management. Sustainable multiple-use forest management places high expectations on foresters, and yet to increase production from tropical moist forests, management must not only be intensified but diversified. Integrated,

multipurpose forest management requires a reliable scientific database, which is still largely unavailable for most forest blocks. There is a paucity of data on the silviculture of most indigenous species—the silvicultural systems tried in tropical forests have been based on field observations rather than on well designed and properly executed silvicultural experimentation. Detailed knowledge and understanding of ecosystem functions and structural dynamics as well as the knowledge of the special uses of their species components possessed by the indigenous people of these areas in the tropics are lacking (Oteng-Yeboah, 1994). Moreover, foresters trained in traditional forestry are ill-equipped to collect, analyze, and synthesize data on the broad range of non-timber forest products (NTFPs) utilized by rural communities; and this poses a great challenge to training and research institutions. There are serious taxonomic impediments because very few trained taxonomists are found in the region. Measurement of quantitative and qualitative characteristics of NTFPs is problematic as is standardization of measurements.

Despite the obvious data constraints, efforts are being made (although still at a modest scale) to address the problem. An appreciable level of support is coming in the form of donor-assisted conservation projects targeting key forest areas. International aid agencies and NGOs such as the World Bank, CARE international, German Agency for Technical Cooperation (GTZ), Danish International Development Agency (DANIDA), Finnish International Development Agency (FINNIDA), Swedish International Development Authority (SIDA), World Conservation Union (IUCN), World Wide Fund for nature conservation (WWF), African Wildlife Foundation (AWF), European Commission (EC), NORAD, several local NGOs, and community-based organizations (CBOs), etc., are actively involved in the region, funding specific projects or helping to build partnerships among national institutions and/or within local communities.

Through the support of these agencies, collaborative forest management initiatives are being built to involve local communities in forest conservation in specific localities. In Uganda, for instance, when gazetted forests came under the management of Uganda National Parks in the early 1990s, there was increased hostility from the local people who perceived the higher protection status of forest as a deliberate move by the government to deny them resources they have always depended on. With donor support, collaborative mechanisms are being built to involve local people in the management of forest resources. Other examples of evolving collaborative forest conservation projects in the region include a SIDA-funded Dura-Haitemba Miombo woodland conservation project in Babati District, Tanzania; and a GTZ-funded, integrated natural resource project in Shimba Hills, Kenya, through the National Forestry Department of Kenya and Kenya Wildlife Service. These forest-specific projects help not only to build collaboration, but also strengthen the capacity of the implementing departments and generate resource data that form the basis of sustainable forest management.

Forest management at a regional level can also be improved through collaborative research and networking. There should be a more spirited research collaboration among training and research institutions within and between respective countries in the region. Networking would encourage the sharing of information, for example, on silvical characteristics of a wide range of tree species, growth rates, non-timber forest products and their quantitative assessment, market forces, and forest resource assessment and monitoring systems. The question of criteria and indicators for

sustainable forest ecosystem management is yet to receive attention in East Africa. It is anticipated that the just-approved GEF-funded regional project will contribute substantially to building research networking in the region.

Institutional Arrangements for Collaborative Forest Management

The issue at present is not whether active involvement of rural communities is crucial in successful management of forests both in gazetted and non-gazetted forest areas. It is often neither politically feasible nor ethically justifiable to exclude poor people who have only limited access to resources from parks and forest reserves without providing them with alternative means of livelihood. Various projects and programs are attempting to mitigate this inequity by linking protected-area management with social and economic development in local communities. Like in many other parts of the world, collaborative forest management initiatives in East Africa are still evolving; it will be sometime before concrete models begin to emerge. This evolutionary process faces a number of key impediments: namely bureaucratic rigidity and the sectoral nature of government agencies, and harmonizing global conservation goals and donor conditions vis-a-vis national goals and sovereignty. While there is an appreciable level of understanding and convergence of national and global conservation objectives, the interactive processes at the local level with communities is much less understood, and often ill-defined. Virtues of participatory approaches are often lauded, but conservation projects continue to be designed in most part with little or no real participation of the local people. This is fundamentally the case because the devolution process is not always embraced by all stakeholders, and in any case is yet to lead to real community empowerment in the East African region. There are a number of questions that remain unanswered:

- What precise roles will communities play in relation to other stakeholders? More specifically, is community participation merely in terms of agreeing with conservation and management objectives?
- Which management model exists (or can be developed) in terms of stakeholder involvement that will be desirable for forest conservation in a protected area? Non-protected areas? What institutional changes (and is there political support for these) will be required?
- How do we transform non-homogeneous communities into "entities" with a common set of interests for conservation purposes?
- Under collaborative management arrangements, will sufficient administrative and technical capacity be built within communities or will these continue to come from outside?
- To what extent will the capacity of implementing government agencies be utilized in community-based conservation and what level of re-orientation and re-training will be required for these agencies to function effectively under a collaborative, essentially cross-sectoral (as opposed to sectoral) arrangement with local communities?

Collaborative forest management calls for some fundamental institutional changes. Institutional integration would be needed. Such integration is expected to be a slow process or even unattainable because it involves radical shifts from what is known i.e., "business as usual," to a new institutional framework that may not be well understood in the first place, leave alone being accepted. A pragmatic approach from a conservation standpoint, is to strengthen coordination mechanisms at the national level, and more importantly at the local level to avoid conflicts and potential confusion arising from uncoordinated delivery of forest resource conservation and management packages (Figure 1).

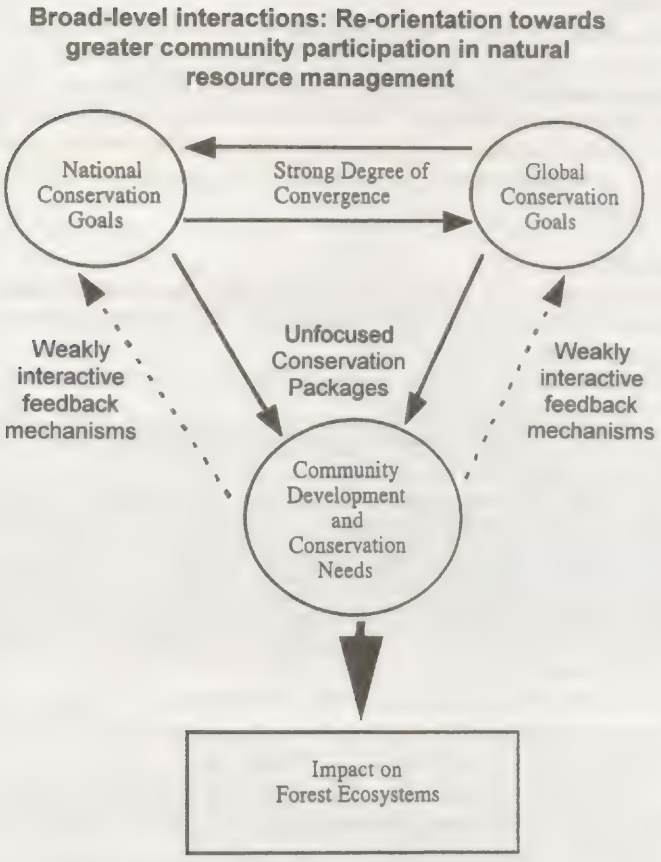

Broad-level interactions: Re-orientation towards greater community participation in natural resource management
National Conservation Goals
Strong Degree of Convergence
Global Conservation Goals
Weakly interactive feedback mechanisms
Unfocused Conservation Packages
Weakly interactive feedback mechanisms
Community Development and Conservation Needs
Impact on Forest Ecosystems

Figure 1. Diagram showing interactions between global, national, and community conservation needs.

Donor agencies need to move away from the culture of "imposing conditions" as well as being more participatory. Apart from direct funding of activities on the ground (which constitute tangible and visible outputs to all stakeholders), donor agencies are often required to fund less obvious and yet very critical aspects such as supporting an enabling environment (e.g., promoting an enabling policy by building partnerships among local, national, and international institutions); and supporting institutional change (e.g., transformation of institutional structure, redefining roles and responsibilities). Donors would also need to orient their policies in accordance to these new stakeholder partnerships. In a recent Commonwealth Forestry Conference held in Zimbabwe (May 10–17, 1997), it was very apparent that donor agencies need to be more participatory, and there is a need to revisit project management procedures in response to the flexibility required in shared or collaborative forest management initiatives.

CONCLUSIONS

Forest resources in East Africa are important reservoirs of plant germplasm. The forests are, however, decreasing in area and degraded in quality and productivity. Conservation and sustainable utilization of plant resources in the region are influenced by a complex interaction of ecological, technical, and socioeconomic and political factors operating at different levels. Forest ecosystem management strategies should be centered upon a good understanding of these interactions, and resource channeling refocused accordingly.

REFERENCES

Godoy, R. A. and Bawa, K. S. 1993. The economic and sustainable harvest of plants and animals from tropical forest: Assumptions, hypotheses and methods. Economic Botany 47(3): 215–219.

IUCN. 1996. Forest cover and forest reserves in Kenya: policy and practice. IUCN, Eastern Africa Regional Office.

Japman, C. J. 1995. Tropical deforestation: a socio-economic approach. Earthscan Publications Ltd., London.

Lovejoy, T. E. 1988. Will unexpectedly the top blow off? Bioscience 38(10): 722–726.

MENR. 1994. Kenya Forestry Master Plan: Development and Programmes. Ministry of Environment and Natural Resources, MENR, Nairobi, Kenya.

Oteng-Yeboah, A. A. 1994. DNA Bank Depositories in developing countries: The way forward in Sub-Saharan Africa. *In*: Conservation of Plant Genes II: Utilization of ancient and modern DNA, R. P. Adams, J. S. Miller, E. M. Golenberg, and J. E. Adams, eds. Missouri Botanical Garden.

Rodgers, W. A. 1993. The conservation of the forest resources of eastern Africa: past influences, present practices and future needs. *In*: Biogeography and Ecology of Eastern Africa, J. C. Lovett and S. K. Wasser, eds.

Rodgers, W. A. and Homewood, K. M. 1982. Species richness and endemism in the Usambara mountain forest, Tanzania. Biological Journal of the Linnean Society 18: 197–242.

Rowe, R., Sharma, N. P. and Browder, J. 1992. Deforestation: problems, causes and concerns. *In*: Managing the world forests: looking for balance between conservation and development, N. P. Sharma, ed. Kendall/Hunt Publishing Company, Iowa.

Simons, A. J. 1996. ICRAF's strategy for domestication of non-wood tree products. *In*: Proceedings of International Conference on Domestication and Commercialization of Non-timber Forest Products in Agroforestry Systems, R. R. B. Leakey, A. B. Temu, M. Melnyk, and P. Vantomme, eds. Non-Wood Forest Products 9, FAO, Rome.

Wass, P. 1995. Kenya's Indigenous Forests. Status, Management and Conservation. IUCN, Gland, Switzerland and Cambridge Univ. Press, UK.

Wasser, S. K. and Lovett, J. C. 1993. Introduction to the biogeography and ecology of the rain forests of eastern Africa. *In*: Biogeography and Ecology of the Rain Forests of Eastern Africa, J. C. Lovett and S. K. Wasser, eds. Cambridge Univ. Press, UK.

SUSTAINABLE USE AND CONSERVATION OF ARID AND SEMI-ARID LAND (ASAL) TREE SPECIES IN KENYA: THE CASE OF *MELIA VOLKENSII*

Titus K. Mukiama
Department of Botany, University of Nairobi
P.O. Box 30197, Nairobi, Kenya

Richard W. Mwangi
Department of Zoology, University of Nairobi
P.O. Box 30197, Nairobi, Kenya
&
H. Rembold
Formerly of Max-Planck Institute
Munich, Germany

SUMMARY

A survey of the tree *Melia volkensii* conducted in the arid and semi-arid zone of eastern Kenya and northeastern Tanzania showed that the species thrived in sandy soils at altitudes between 800–1400 m. Tree densities of over 80/ha were estimated in the Kianjiro Hill area of the Mbeere district and Mwatate town. Up to 2800 mature trees were estimated to be in the zone mainly in agroforestry systems, with a fruit production capacity of about 473 tons per year. Such a quantity is sufficient to support an insecticide production industry based on the triterpenoids concentrated in the seeds. Such an incentive, plus other benefits such as timber production, can motivate farmers to conserve the tree and yet use it sustainably.

INTRODUCTION

Arid and semi-arid lands (ASALs) form a rather large proportion of Kenya's land surface, comprising more or less ¾ of the total land area. ASALs cover the entire districts of Turkana, Samburu, West Pokot, Baringo, Marsabit, Isiolo, Mandera, Wajir, Garissa, Tana River and Mwingi. In addition, large parts of Lamu, Mbeere, Kitui, Machakos, Taita-Taveta, Kajiado, and Narok fall within this category. Most of these areas are sparsely populated, and have largely been inhabited by pastoral communities practicing a nomadic way of life.

Until recently, an equilibrium existed between the utilization of natural resources by the residents and their natural rate of regeneration, such that people were able to use them sustainably without major crises. This balance was most likely maintained through the practice of complex traditional cultural/indigenous processes designed to conserve and nurture the environment. In present times, however, this equilibrium is either seriously threatened or altogether disintegrating due to several factors, all impacting from pressures of a high rate of population growth and the subsequent lack of the basic means of livelihood. An unsustainable demand for biological resources is exacerbated by a lack of suitable alternatives and a poor enabling environment sustained by a weak regulatory capacity and lack of knowledge of resources and their use.

In ASALs, the fragility of the environment requires that ecosystems, in general, and plant species, in particular, are used for human benefit in ways that ensure their viability and preservation. In Kenya, ASAL tree species are used in such direct and

diverse ways as the provision of building and fencing material, medicine, browse, food, utensils, ropes, fuelwood and shade. Other uses include the production of gums and honey. More indirectly, ASAL trees are highly regarded for their perceived role in rain attraction, and for acting as wind breaks.

Among the species that may be found in Kenya ASALs are: *Acacia tortilis, A. albida, A. eliator, A. senegal, A. reficiens, A. nubica, A. mellifera, A. paolii, Cordia sinensis, Dobera glabra, Calotropis procera, Ficus sycamorus, F. populiafolia, Tamarindus indica, Combretum aculeata, Zizyphus mauritiana, Salvadora persica, Hyphaene coriaceae, Balanites pedicellaris, B. orbicularis, Berchemia discolor, Delonix alata, Diospyros scabra, Boscia coriacea, Commiphora trothae, Euphorbia cuneata, Abutilon hirsutum, Jatropha dichton, Cadaba rotundifolia* and some species of *Grewia* and *Cassia*. *Melia volkensii* is common in the ASALs of eastern Kenya.

Though the concept of conservation and sustainable use is not entirely new to this country and region, its importance was greatly highlighted and its urgency stressed by the Convention on Biological Diversity, to which Kenya is party and signatory. Article 10 of the convention states that each contracting party shall, as far as possible and as appropriate:

- Integrate consideration of the conservation and sustainable use of biological resources into its national decision-making;
- Adopt measures relating to the use of biological resources to avoid or minimize adverse impacts on biological diversity;
- Protect and encourage customary use of biological resources in accordance with traditional cultural practices that are compatible with conservation or sustainable use requirements;
- Support the local population to develop and implement remedial action in degraded areas where biological diversity has been reduced; and
- Encourage cooperation between its governmental authorities and its private sector in developing methods for sustainable use of biological resources.

In this paper, we examined how *Melia volkensii* may be used as a sustainable, but also conserved species in the ASALs of eastern Kenya.

THE CASE OF *MELIA VOLKENSII*

Taxonomy and Ecological Zones

Melia is one of the nine genera in the Family *Meliaceae* (Beentje, 1994). In his monograph of the genus, Mabberley (1984) considered *Melia volkensii* Gurke a distinct species within the family *Meliaceae*. Locally, *M. volkensii* is the only indigenous species in the genus, and is known in various languages as Mukau (Kikuyu, Kamba), Pandaburi or Mukumbutu (Taita), and Mkowe (Taveta). Mature trees reach heights of between 6 to 20 m. The bark of the tree is gray, the leaves light green, and the flowers a light purple to white. Immature fruits are green, yellow when ripe, and brown when dry.

Melia volkensii naturally grows in land only very locally suited for agriculture at altitudes of between 350 and 1700 m above sea level. The woody bushland vegetation is dominated by *Commiphora*, *Acacia*, and allied genera that are mostly shrubby in habit. The natural species range of *M. volkensii* is reported to extend from southern Ethiopia through northern and eastern Kenya into northern Tanzania (Beentje, 1994).

Field Survey The field survey covered areas of known natural growth potential of *M. Volkensii*, but focused on areas with significant tree densities, with significant agroforestry practices, that traditionally practice agriculture and that are secure and socio-politically stable. The approach adopted was to analyze the existing situation on the ground with regard to quantities present by as much as possible arriving at logical and reasonable estimates. The survey covered areas of eastern Kenya through Embu, Mbeere, Machakos, Makueni, and Taita-Taveta districts, and across the border into northeastern Tanzania (Figure 1).

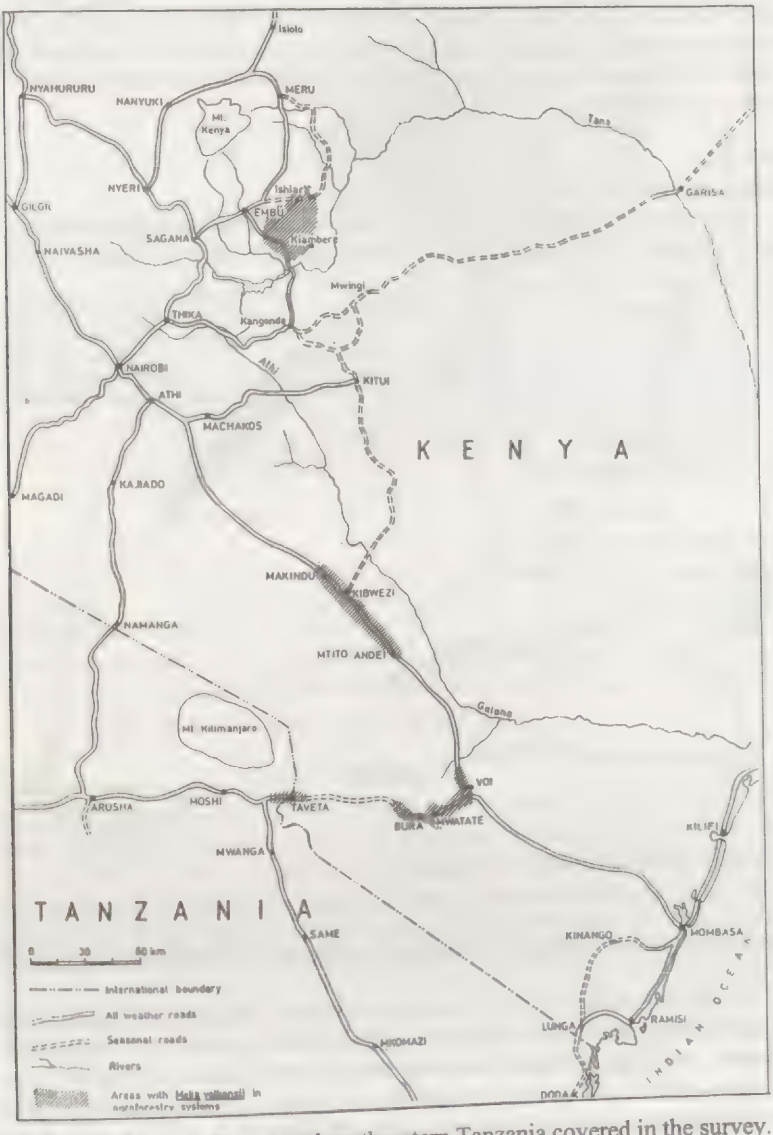


Figure 1. Areas of eastern Kenya and northeastern Tanzania covered in the survey.

Due to the non-random distribution of the trees, it was not possible to adopt standard techniques used in ecological vegetation surveys. A modification of the walk-through transect method (Mueller-Dombois and Ellenberg, 1974), incorporating a "drive-through" variation, was used. There were slight variations depending on the pattern of distribution of the trees (i.e., in agroforestry systems, aesthetic systems, or naturally growing trees.

For purposes of estimating the industrial potential of *M. volkensii* fruit extracts, dry yields per kg of fresh fruit were estimated. In order to predict the agronomic parameters of *M. volkensii* for agroforestry, soil analysis, climate data, and propagation details were obtained. Other information, including socioeconomic considerations, was obtained with the assistance of a questionnaire. Details of the questionnaire are available elsewhere (Mukiama, 1997).

RESULTS

Distribution and Densities

The distribution of *M. volkensii*, showing localities of significant density, is shown in Figure 1. The details of density distribution are shown in Figures 2 and 3.

Figure 2. *Melia volkensii* density in southeastern Kenya and northeastern Tanzania.

In our estimation, areas of very high density had over 80 trees per hectare, those with high density had from 40–79 trees, and those with low densities had under 40 trees per hectare. Very high and high densities occurred in areas practicing intense agroforestry, while low densities included localities with aesthetic stands of trees. Wild growing trees generally occurred in much lower densities.

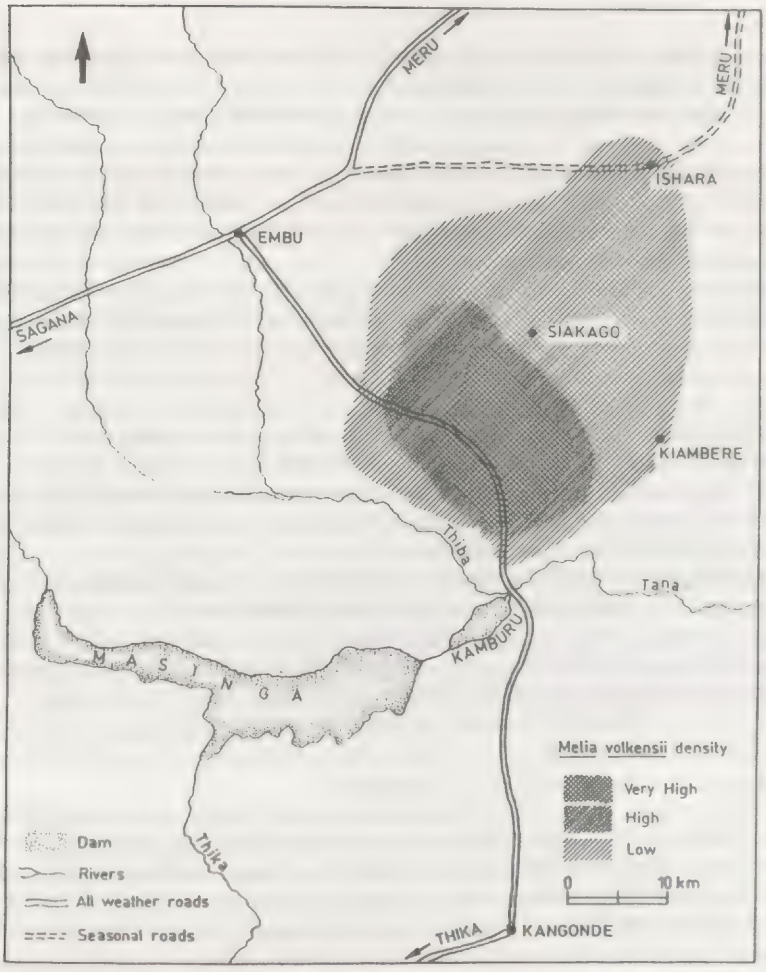


Figure 3. The density of *Melia volkensii* in the Mbere district.

Production Estimates

Our estimates of mature trees per district gave a total of 2800 for Mbeere, 140 for Makueni, 700 for Taita-Taveta and 30 for northeastern Tanzania, with 90% of these trees occurring in agroforestry systems. It is also estimated that a total of 256 kg of fresh fruit could be harvested per average-size mature tree, giving a total of 473 tons of fresh fruit per year for the entire zone. The estimated total weight of dry fruit was 205 tons.

Other Agronomic Parameters

The results of the soil texture analysis showed that 70% of the soil samples were sandy clay loams/sandy loams, while 26% were clay/clay loams and 87% of all samples had a composition of over 40% sand. *Melia volkensii* occurred in altitudes between 800 and 1400 m above sea level. The mean annual rainfall ranges from a minimum of 300

mm to a maximum of 700 mm. Similarly, the annual minimum mean temperature is 14°C, while the mean annual maximum is 34°C.

The seed coat of *M. volkensii* is one of the most resistant known, requiring extreme measures to break to allow germination. In nature, the fruits are eaten and swallowed by wild ungulates whereby the seed coat disintegrates as it passes through the digestive system. The seed is subsequently passed in the dung in a state favorable for germination in the rainy season. Bushfires may also crack the seed coat, and thus make some seeds prone to germination.

In the farms visited, seeds found in goat droppings were claimed to account for most of the seedlings raised. Others grew vegetatively from underground root tubers in the periphery of old trees. Heating of seeds through burning or boiling is another artificial technique reportedly used to break dormancy. There was no evidence that propagation through cuttings is practiced.

Propagation activities were generally at a very low scale, usually practiced by a few individual farmers. No large-scale nursery was seen in areas visited. Farmers generally committed no inputs to support the growth process of their seedlings and trees. No water, mulch, manure, or fertilizer was applied. The only protective measure taken for the seedlings was to keep the goats off.

Seedlings take 7 to 10 years to mature and begin fruiting, depending on the local climatic conditions. Fruiting may occur either after the short rains (October–December), or after the long rains (March–June). Fruits turn yellow upon ripening about 6 months after flowering. They fall off the tree, and thereafter begin the vagaries of the germination process.

Socioeconomic Observations

Association of *M. volkensii* with human settlements

High densities of *M. volkensii* were associated with human settlements, while unsettled areas were characterized by very low densities. The highest densities were found in Mbeere district and Mwatate town, both areas that are highly populated. In the bushland expanses of Makueni and Taita-Taveta, *M. volkensii* was usually found in isolated market centers, railway stations, school compounds, and small shopping centers. Apparently, human crop husbandry was essential for the proliferation of the species.

Agroforestry

The highest densities of *M. volkensii* occurred in areas where agroforestry was an accepted norm (i.e., in Mbeere and Mwatate). Trees were generally given some care from the seedling stage to maturity, and were considered important in agroforestry. In the Makueni district, on the other hand, the practice of agroforestry was poorly developed and tree care was minimal. The majority of mature trees had a generally deformed appearance due to excessive goat browsing and cutting of branches.

Economic and other values

Timber is by far the main economic value of *M. volkensii*. This was particularly so in Mbeere and Mwatate, where trees were carefully nurtured for this purpose. High grade timber was normally obtained from trees about 20 years old. The timber is termite-resistant. At Munyori village in Mbeere district, our questionnaire revealed that:

- a single aged tree with a straight trunk costs approximately K.Sh. 2000;
- a piece of timber measuring 1 m X 30 cm X 2.5 cm costs approximately K.Sh. 145;

- a seedling with developing root tubers costs up to K.Sh. 50;
- the estimated cost of 1 kg of fresh fruit was K.Sh. 5.

Generally, following timber production, the leftover wood was used for beehive construction, fencing material, and firewood.

The other traditional uses of *M. volkensii* noted earlier were confirmed in this survey, although in varying degrees. Insecticidal and acaricidal potency of extracts was recognized by all communities in the areas visited. However, active use was not confirmed as modern industrial products have largely eclipsed the widespread use of traditional products. The use of *M. volkensii* as livestock feed was most pronounced among the Kamba people of Makueni district. In the other districts, only fallen fruit or the remains of felled trees were available to livestock.

Conservation and Sustainable Use

Conservation *per se* is not an attractive proposition to most communities. However, when there are clear benefits or incentives arising, then there is motivation to conserve. Utilization of natural resources is therefore a central theme in conservation. This utilization, however, must be sustainable (i.e., at rates that do not exceed the creation of substitute capital resources). It must also ensure the maintenance of essential ecological processes and balanced development that maintains the sum of options available to future generations.

Direct Benefits

In the case of *M. volkensii*, direct benefits available through conservation are timber for building and cash, fencing materials, firewood, medicine, insecticide/acaricide, animal feed, wind-breaking, and shade.

Indirect Benefits

Melia volkensii has been shown to be a species very suitable for land reclamation and environmental conservation in ASALs because it possesses unique qualities suitable for these areas. It remains green most of the year and is pest-resistant. It has also been found very suitable for reforestation and agroforestry in ASALs due to its physiological and environmental adaptability.

Potential Uses

The most important potential use of *M. volkensii* is the industrial production of pharmaceutical products. Available reports indicate that fruits of *M. volkensii* contain triterpenoid compounds, which are highly insecticidal (Mwangi, 1982; Mwangi and Rembold, 1987, 1988; Mwangi and Mukiama, 1989; and Nasseh et al., 1993). Our production estimates of a total of 2800 available mature trees, producing 473 tons of fresh fruit per year, which in turn can yield 205 tons of raw material, indicate that the available crop of *M. volkensii* may provide a suitable supply base for industrial exploitation. With the sale of fruit as an incentive, it is expected that farmers in ASALs would considerably increase the level of agroforestry and reforestation of *M. volkensii*. Although there is no feasibility report available to justify capital investment in the processing of *M. volkensii* fruit extract, a high level of interest has already been shown by some parties (Mukiama, 1997).

CONCLUSIONS

Sustainable use of any biological resource should be seen in the context of overall sustainable development, i.e., "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). The outcomes of this process must be seen as being socially desirable, especially viable, and ecologically sustainable.

In this regard, the sustainable use and conservation of *M. volkensii* should be considered in the context of the sustainable use of other species, and the overall development of ASALs. For immediate and practical purposes, however, it is clear that *M. volkensii* is an ideal species to promote in these areas. It has a high potential for agroforestry and reforestation, which individuals, communities, NGOs, and government may exploit. Efficient ways of propagation need to be investigated and developed, particularly the possible use of cuttings and tissue culture. This will enable the development of organized tree nurseries.

The benefits of conserving *M. volkensii* far outweigh any liabilities. To the farmers, only minimal investment is required to start a plantation. Financial incentives are already available in timber sales, and more may be expected from possible industrial processing of fruit extracts. However, this will need stakeholder involvement, i.e., government, local communities, experts, and prospective industrialists, in order to set out the modalities of the undertaking, and define the role and benefits of all parties.

REFERENCES

Beentje, H. J. 1994. Kenya trees, shrubs and lianas. National Museums of Kenya, Nairobi, Kenya.

Mabberley, D. J. 1984. A monogragh of Melia in Asia and the Pacific. The history of White Cedar and Persian Lilac. Garden's Bulletin 37: 49–64.

Mueller-Dombois, D. and Ellenberg, H. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York.

Mukiama, T. K. 1997. Ground survey, estimation of tree densities, and production potential of *Melia volkensii* in Kenya and Northern Tanzania. GTZ Consultancy Report.

Mwangi, R. W. 1982. Locust anti-feedant activity in fruits of *Melia volkensii*. Entomol. Exp. Appl. 32: 277–280.

Mwangi, R. W. and Mukiama, T. K. 1989. Evaluation of *Melia volkensii* extract fractions as mosquito larvicides. J. Am. Mosq. Control Assoc. 4: 442–447.

Mwangi, R. W. and Rembold, H. 1987. Growth-regulating activity of *Melia volkensii* extracts against larvae of *Aedes aegypti*. *In*: Proc. 3rd. Int. Neem Conference, H. Schmutterer and K. R. S. Ascher, eds. Nairobi, Kenya.

Mwangi, R. W. and Rembold, H. 1988. Growth inhibiting and larvicidal effects of *Melia volkensii* extracts on *Aedes aegypti* larvae. Entomol. Exp. Appl. 46: 103–108.

Nasseh, O.,Wilps, H., Rembold, H. and Krall, S. 1993. Biologically active compounds in *Melia volkensii*. J. Appl. Entomol. 116: 1–11.

World Commission on Environment and Development. 1987. Our Common Future, Oxford Univ. Press, Oxford.

CONSERVATION OF PLANT GENETIC RESOURCES IN KENYA

M. Isahakia, E. Obunga, Y. Morimoto, B. Kamondo and R. Aman
National Museums of Kenya, P.O. Box 40658
Nairobi, Kenya

SUMMARY

Plant Genetic Resources (PGR) in Kenya are increasingly threatened by the rapid increase in human population, which has in turn exerted pressure on natural vegetation through overgrazing, firewood collection, tree poaching, clear felling (for agriculture and settlement), and replacement with exotic plantations. In some cases, indigenous trees and food plants have become endangered, extirpated, or extinct as a result of these threats. Concerted efforts are required to conserve PGR if we are to prevent the irretrievable loss of these resources and other life forms that they support. This paper presents an overview of the status of ongoing activities aimed at conservation of PGR in Kenya. It lists the key institutions involved in these activities and addresses their institutional mandates, PGR-related research programs, infrastructural and human capacities, and constraints and challenges facing them. Information was gathered through personal interviews, site visits, observations, and a literature review. The study revealed that some of the institutions lack basic facilities in germplasm storage while several with existing facilities were severely compromised by maintenance problems resulting from lack of financial resources. A conspicuous observation was overemphasis on the storage of seed to the exclusion of micropropagation facilities. In addition to financial woes, a serious constraint in the development of effective and relevant research programs was recognized to be the lack of adequately trained human resources. A glaring absence of serious strength—complementing research collaboration between institutions was noted and attributed to overlapping research mandates, absence of legal or institutional frameworks for collaboration, inadequate knowledge on the potential for collaboration, incompatibility of databases, and the inability of the National Plant Genetic Resources Committee (NPGRC) to forge greater cooperation.

INTRODUCTION

Kenya contains a rich diversity of plant species. Approximately 7000 species have been identified, but it is estimated that there are between 8000 and 9000 plant species. Among these, Kenya has recorded 45 species of wild vegetables, 200 species of wild fruits and several wild forage grasses, legumes, browse plants, cereals, pulses, and oil crops. Among all the species, at least 392 are national endemics and 336 are regional endemics (IUCN, 1990; Muthoka, 1995) (Table 1).

In recent years, the human population increases and subsequent demand for plant products and land for settlement and farming has threatened PGR, and exotic crop species are rapidly replacing indigenous crops. For example, the demand for land has resulted in a direct loss of forest land at a rate of 5000 ha per annum (KIFCON, 1994). Some indigenous crop species such as *Dioscorea munitiflora* (yam) are also

Table 1: Distribution of rare/endangered and endemic species in Kenya (Adapted from Beentje, 1988).

Vegetation type	Total species	Rare/ Endangered spp.	Endemic spp.
Coastal forests	32	25	12
Taita hill forests	10	6	7
Central Kenya (dry forests)	9	6	6
Northeast Kenya	10	2	3
Central Kenya (riverine)	5	4	3
Northern and Central hills	7	-	2
Coastal (not forest)	10	1	-
Coastal (littoral thicket)	2	2	-

threatened as local people introduce exotic and hybrid species in their place. Yet these indigenous varieties are important for the maintenance of genetic stocks and improvement of seed in Kenya. The survival of species will therefore depend on the effectiveness of conservation activities.

Threatened species include numerous orchids, aloes, and tree species such as *Dalbergia melanoxylon* (Oldfield, 1993). One-hundred and fifty-eight (158) species of woody plants are threatened, 104 in the closed forests, 46 from the savannas, and 3 from the moorland (Wass, 1995).

In order to conserve our PGR, a number of institutions in Kenya are engaged in PGR conservation activities. However, the level of inter-institutional cooperation, even in areas of common interests, has not been fully explored. As is common with developing countries, the case for plant resource conservation in Kenya has not been articulated enough to bring it to the forefront along with other competitors for land and financial allocation as well as public appreciation. Recent events such as the Rio Earth Summit (1992) and the signing of the Convention on Biological Diversity (CBD) have helped focus political attention to conservation issues. Locally, the National Environmental Secretariat (NES) has formed a multi-institutional biodiversity committee to work toward implementing the country's obligation under the CBD. It carries out Environmental Impact Assessment (EIA) and has up to the present carried out EIA in 15 districts (Marshall et al., 1996). It is also involved in policy articulation and provision of direction on the CBD. Non-governmental organizations and private groups support conservation by specific activities while international organizations like IUCN provide logistical and technical support.

Conservation *per se* has a long historical record in Kenya, but a systematic approach to the issue is very recent, dating to 10 years ago with the establishment of the Gene Bank of Kenya and the holding of a Workshop on PGR in 1987. The workshop defined the responsibilities in PGR conservation among Kenyan institutions while appreciating the conservation mandates bestowed upon other organizations including the Forest Department (FD), Kenya Wildlife Service (KWS), National Museums of Kenya (NMK), by Acts of Parliament (Beentje and Khayota, 1989). The workshop was an important step forward, although it did not embrace non-governmental stakeholders of PGR.

Institutional mandates

- The Kenya Agricultural Research Institute (KARI) has the responsibility of storing crop germplasm and wild relatives of crops;
- Kenya Forestry Research Institute (KEFRI) conserves forest genetic resources and ornamentals;
- NMK, besides keeping dry plant specimens, has been delegated duties of *in situ* and *ex situ* conservation of rare, endemic, or threatened plant species not targeted by other institutions.

Conservation Approaches/Strategies

In Kenya, PGR conservation is largely implemented through two conventional approaches: *in situ* and *ex situ* and responsibilities as shown in Table 2.

Forestry Department (FD)

The FD conservation effort is backed by the Forest Act, Chapter 385. The Act empowers the FD to map forests and forest reserves and manage these on behalf of the state. Historically, Kenya lost much of its indigenous plant biodiversity to compensatory forestry that replaced indigenous forests with fast-growing exotics. The present decline in indigenous forest is through conversion of forest to agricultural lands and illegal harvest for fuelwood and charcoal (DANIDA, 1989). Although a 1986 Presidential directive forbids the felling of indigenous trees, it is largely ignored and its overall conservation impact unknown (WCMC, 1988). The conservation efficacy of the present Forest Act and Forest Policy has been found wanting. Amendments to both have been made and await Ministerial consent. Once consented, any excision will be sanctioned depending on the outcome of an environmental impact assessment.

In an attempt to improve on its conservation role, the FD through the Kenya Indigenous Forest Conservation (KIFCON) project has carried out a national inventory of all natural forests to establish conservation priorities and management recommendations for inclusion in the Forestry Master Plan. Target areas included the Transmara, Mau, Kakamega, and Arabuko-Sokoke forests. All areas are threatened and considered to be biologically significant.

Several conservation projects have since been discontinued and are now ongoing in the FD. These include the Conservation and Management of Indigenous Forests of Mt. Kenya (COMIFOR), Integrated Natural Resource Management at Shimba hills, and the Conservation and Management projects of Arabuko sokoke, Kakamega, and Nandi

Table 2. Role of various institutions in *in situ* conservation (adapted from IUCN, 1990).

INSTITUTION	ROLE
Forest Department	Enforcing through legislation the bulk of conservation sites in Kenya (mapped forests and forest reserves);
Kenya Wildlife Service	Managing all the national parks and game reserves in collaboration with the local county councils in some areas;
Kenya Forestry Research Institute	Generating information on sustainable management of indigenous forest, vegetative propagation;
National Museums of Kenya	Herbaria collections, plant taxonomy, plant inventories, vegetative propagation, coastal forest conservation;
Department of Remote Sensing and Resource Survey	Monitoring of range resources, and high potential plant resources, as well as sources of forage for animals and woodfuel in order to detect condition and trend (GIS in use);
Institutions of Higher Learning	Manpower development and research to support conservation and herbaria collections, collection and storage (transfer to *ex situ*);
National Environmental Secretariat	Carrying out Environmental Impact Assessment at the district level; coordination of research; policy articulation and provision of direction on the Biodiversity Convention;
IUCN	Help in setting up practical projects and sourcing for funding and help in their implementation

forests. All these project are complemented by a mammoth Project on Sustainable Forest Management (PSFM), which is a multidisciplinary project being implemented in the same areas, and aims to improve performance of the total forestry sector. The FD has also benefited from the East African Regional Biodiversity UNDP/FAO/GEF project, which has strengthened its capacity to implement conservation work through training of staff, and provision of radio communication and transportation facilities.

Kenya Wildlife Service (KWS)

It is estimated that national parks and national reserves in Kenya cover about 44,000 km^2, 7.5% of the country's area. The conservation jurisdiction spanning from the alpine flora to montane forests to lowland forests is under the Kenya Wildlife

Service. Most protected areas are located in the semi-arid regions of the country where savannas dominate. Wetlands and the arid north as well as several important forests are not adequately protected due to factors ranging from encroachment to insecurity. Some areas are managed in collaboration with the local county councils. The plant resource is managed in a similar manner as that managed by the FD. A few parks and forests such as Arabuko sokoke and mountain forests are indeed under dual management. A Memorandum of Understanding to harmonize action and management plans has been signed between the two institutions. This balances the exploitation of the forest versus the conservation of biodiversity and promotion of eco-tourism.

Kenya Forestry Research Institute (KEFRI)

To support FD's ability to carry out *in situ* conservation, KEFRI (1992) has undertaken various research projects. KEFRI has carried out extensive inventory on the bamboo vegetation type that is threatened by indiscriminate extraction. It has researched the introduction of alternative cultivated types to ease pressure on the indigenous ones, and a few demonstration plots have been established in Kakamega and the coast. A KEFRI project examining the sustainable management of indigenous forest is coordinated from Muguga. With government funds, 29 permanent plots have been established to study forest ecology; 14 of them are situated around Mount Kenya and contain Meru oak (*Vitex keniensis*), and the other 5 are at Arabuko Sokoke Reserve on the coast in order to study species composition and forest ecology. The World Wide Fund for Nature (WWF), ODA, and the Government of Kenya have contributed to this project, which has been carried out in collaboration with the East African Herbarium of NMK (Marshall et al., 1996).

National Museums of Kenya (NMK)

As alluded to earlier, NMK, under the auspices of the Antiquities and Monuments Act (1983), undertakes evaluations for sites to be mapped as national monuments and seeks legal protection for sites that are botanically rich yet too small in area to be included within the National Protected Areas Network. To date, over 20 sacred forests (Kayas) renowned for their high levels of species endemism have been mapped at the Kenyan coast, and strategies for sustainable utilization of resources agreed upon with the adjoining community. NMK has established a special Coast Forest Conservation Unit (CFCU) to work together with communities to manage these important habitats (ICPPGR, 1995). Recently, parks around Nairobi have been mapped as monuments as they come under increased threat from alternative uses such as offices, hotels, and housing estates. Uhuru Park, Central Park, City Park, and Uhuru Gardens are parks with rich biodiversity. Some areas like Mutomo Hill Plant Sanctuary have been set aside and serve to conserve and protect plants in their natural habitats.

Vegetation inventories and mapping of plant communities form essential tools in plant resource conservation. Conducting vegetation inventories for a country with such varied habitats as Kenya is an enormous task that requires qualified personnel and considerable funding. Through the East African Herbarium and its Plant Conservation and Propagation Program, the NMK has undertaken inventory work on sensitive habitats such as those threatened by quarrying at the coast and hotel expansion.

Inventory projects assisted in identifying the Coastal Kaya forests (Robertson and Luke, 1993) and Taita Hills (Beentje, 1988) as centers of plant diversity and therefore in need of conservation through gazettement under the Antiques and Monument Act. However, this area has not yet been gazetted, but NMK has moved in to salvage the germplasm through the alternate less preferable method of *ex situ* conservation. In fact, monitoring inventories on rare, threatened, and endemic PGRs, even when under protection, is a regular exercise at NMK. *Milletia leucantha* Vatke and *Baphia keniensis* Brumnit have been receiving regular monitoring in Tsavo and Meru national parks, respectively.

With a reference collection of about 800,000 specimens from 7000 plant species from East Africa, the herbarium is well equipped with the primary data necessary to conduct further inventories. The herbarium is also involved in compiling checklists of plants of various habitats in the country. Already checklists have been completed for no less than 20 habitats. From these checklists, various data can be generated, such as the species composition, the levels of endemism, and information about endangered species. KEFRI and NMK have the in-house capacity to use isoenzyme and molecular techniques to address biodiversity at the species and gene level. This line of research will enable more appropriate conservation and should answer the complex problem of determining how small an indigenous patch of forest can be made and still maintain a viable population and maintain its genotypic integrity.

Ex situ Conservation

The elaborate legislation notwithstanding, the *in situ* conservation program in Kenya is not infallible. Legal and illegal actions witness the loss of habitats, loss of species, and the loss of important genotypes within a species. Moreover, the highest level of plant diversity exists outside protected areas where land ownership is yet to be defined, further attenuating the efficacy of *in situ* conservation.

To complement *in situ* conservation efforts, *ex situ* conservation is being practiced mainly through seed banking and, to a minor extent, through botanical gardens, field genebanks, and *in vitro* conservation. *Ex situ* conservation addresses various plant species but, until very recently, emphasis has been on agricultural crops and their wild relatives. *Ex situ* conservation has a long historical record in Kenya. But, as alluded to earlier, a systematic approach to the issue is very recent, dating to 10 years ago with the establishment of the Gene Bank of Kenya and the holding of a workshop on Plant Genetic Resources in 1987. The ability to conduct *ex situ* conservation of genetic resources is fairly well-developed, but considerable genetic resources remain to be explored and collected.

Genebank of Kenya (GBK)

The GBK has the largest long-term seed storing unit. The GBK addresses all cultivated crops, their varieties, land races, obsolete elite varieties, wild relatives of cultivated crops, indigenous food crops, pastures, and forages. The areas of high potential faced with high genetic erosion have been ranked highest for exploration and collection missions. Within these areas, indigenous crops, such as sorghum and millets, facing imminent replacement by introduced crops, have been rescued. These areas have been well-collected and only need gap-filling collections. Presently, priority collecting

is shifting to the marginal areas where new threats in the form of influx of refugees is causing genetic erosion of the plant stocks, especially on pastures and forages.

The GBK strives to follow the procedures and standards advocated by the International Plant Genetic Resources Institute (IPGRI) and International Seed Testing Association (ISTA) in handling its germplasm. For indigenous species not covered by ISTA, the GBK is carrying out research to develop the appropriate standards. The GBK currently holds slightly over 40,000 accessions of cereals, pulses, oil crops, local vegetables, fiber, forages, root/tuber crops, and fruit trees (Table 3), which are duplicated in various commodity research stations as active collections. The material is not duplicated anywhere else under long-term storage, which is a matter of great concern.

Table 3. The number of GBKs germplasm accessions 1988–1996.

Crop Germplasm	Collected accessions	Donated accessions	Multiple accessions	Characterized accessions	Total conserved	Conserved in the field
Cereals	1,676	7,439	10,324	4,516	9,115	-
Pulses	283	4,640	4,173	1,313	4,923	-
Oil crops	115	1,388	1,580	1,293	1,503	-
Local vegetables	901	112	649	177	1,013	-
Fiber	51	801	612	227	852	-
Forages	499	22,657	11,103	710	23,156	-
Roots/Tuber crops	103	98	-	96	101	201
Fruit trees	16	305	-	-	-	321
TOTAL	3,644	37,743	28,441	8,332	41,387	522

The collection includes 1007 species from 333 genera. This includes duplicate accessions of sorghum and millet from ICRISAT, as the GBK has a regional mandate to store sorghum and millet collections from neighboring countries. The GBK is preparing to implement its global mandate to store simsim (*Sesamum indicum*), white mulberry (*Morus alba* L.), and sweet sorghum (*Sorghum bicolor* L.), which will be deposited from various places in the world (IPGRI, 1995). The GBK management estimates that between 60 and 70% of its workload on *ex situ* conservation is yet to be accomplished.

For those materials difficult to store as seed, and for vegetatively propagated species, the gene bank has established several field gene banks. At Muguga, a sugarcane field gene bank contains accessions of past and present Kenyan cultivated sugarcane varieties, wild varieties of the sugarcane and some accessions from various African countries. At Matuga, accessions of citrus, coconuts, mangoes, bananas, avocados, cashew nuts, and cassava are being maintained. These field gene banks are far from complete as a number of species are yet to be addressed (ICPGR, 1995).

KEFRI, through its seed center, runs a parallel program to that of GBK for all types of forestry tree species.

Other *ex situ* conservation approaches are organized through arboreta/botanic gardens (KEFRI, NMK). Financial support for training needs and banking activities is a constraint.

National Museums of Kenya

The NMK's seedlot accessions include 70 from 10 rare and endangered species stored under a long-term environment and 231 accessions of orchids stored as an active collection (+3°C). The long-term seed storage facilities are not well developed. Currently a domestic freezer cabinet of limited capacity (-20°C) is being used for this purpose. However, the seed technology lab is adequately equipped to cope with seed testing for conservation purposes and research in support of conservation.

The NMK has five botanic gardens scattered in different parts of the country. Most of them do not have representative samples. NMK will correct the anomaly by establishing new botanic gardens that will meet all the required conservation standards. Work is already in progress at Nairobi and Ukunda; these gardens will complement safe storage of plants. The gardens will also promote integration of the public into the conservation program through education. Financial support is being sought from various agencies to forge ahead with this initiative.

In addition to the above major institutions, other institutions are, to a small degree, holding vital plant genetic material in *ex situ* conservation:

- The Nairobi University Faculty of Agriculture has a department of crop science with a number of staff involved in research and conservation of germplasm. It holds ca. 800 accessions of pigeon pea collected from Kenya and Uganda and has over 1500 of its bean accessions deposited with the Horticulture Research Station at Thika. The university also has a small number of accessions of maize and cowpeas, but the most interesting germplasm is that of *Rhizobium*, a collection of the various bacteria used as inoculants for grain legumes, and forage and crop varieties. A similar *Rhizobium* collection (600 strains) is held by KEFRI for rhizobia associated with leguminous trees in Kenya
- Jomo Kenyatta University College has a unique collection of improved varieties of bananas held in *in vitro* storage and in the field garden.
- Coffee Research Foundation for coffee germplasm.
- ICRAF for agroforestry-based plant germplasm.
- Tea Research Foundation for tea germplasm.

CONCLUSIONS

The area of *in situ* conservation is clouded by a lot of unknowns. We are not yet sure of the whole potential of our flora, especially in arid zones, while encroachment, excisions, fires, and game damage decimate these areas. Inventories and research should go hand in hand with practical conservation measures. Of concern are patches of forest in the dry areas like in Marsabit and Samburu; riverine forests and forest patches in private holdings not addressed by any particular project or organizations but suspected to hold unique biodiversity.

- For *in situ* conservation, it is clear that loss of diversity in quite a few of the *in situ* conservation sites continues at an alarming rate. The protection accorded these areas needs to be improved. Community involvement needs to be explored.
- *Ex situ* conservation needs support and backing from research. Although donor support will be required, the country should show a commitment to conservation by voting a reasonable amount of capital to support the efforts. Participants, on the other hand, should collaborate more and avoid unnecessary competition and duplication of efforts.
- The area of data management is still a concern. Considerable data are generated both for *in situ* and *ex situ* efforts. Even within the same organizations, data and information existing in fragmented forms in different offices would result in significant gains if it were consolidated. If information within the institution is organized, then inter-institutional information sharing would be enhanced.
- Collaboration among participants is improving with the signing of the Memorandum of Understanding. However, the role of a committee to address PGR issues in the different Kenyan institutions remains uncertain. Such a committee for Kenya was endorsed in 1987 as a recommendation of the workshop on PGR but somehow never materialized. The NMK has taken the initiative to reactivate the group, which is operating under the name of Plant Genetic Resource Working Group (PGRWG). It is hoped the group will be able to attract the necessary support to be able to transform itself into a permanent attestant in the area of PGR.

REFERENCES

Beentje, H. J. 1988. Atlas of Rare Trees of Kenya. Utafiti. Occasional Papers of the National Museums of Kenya 1: 73.

Beentje, H. J. and Khayota, B. 1989. Proceedings of the Workshop on Plant Genetic Resources. 6–7 July 1987, hosted by National Museums of Kenya and sponsored by International Board for Plant and Genetic Resources.

DANIDA. 1989. Kenya: An Environmental Profile. Ministry of Foreign Affairs, Department of International Development, Copenhagen, Denmark.

ICPGR. 1995. International Conference and Program for Plant Genetic Resource. ICPGR, Kenya. (Draft).

IPGRI. 1995. Newsletter for Sub-Saharan Africa. IPGRI, Nairobi, Kenya.

IUCN. 1990. Biodiversity in Sub-Saharan Africa and its Islands: Conservation, Management and Sustainable Use. Occasional Papers of the IUCN Species Survival Commission No. 6. IUCN-The World Conservation Union: Gland, Switzerland.

KEFRI. 1992. Kenya Forestry Seed Centre. GTZ, Nairobi, Kenya.

KIFCON. 1994. A National Profile of Kenya's Indigenous Forests. Kenya Indigenous Forest Conservation Program, Karura Forest Station, Nairobi, Kenya.

Marshall, N. T., de Saint Sauveur, A. and Njuguna, S. G. 1996. Plant Resources of Eastern Africa: Activities and Sources of Information. IUCN, Eastern Africa Regional Office, Nairobi, Kenya.

Muthoka, P. N. 1995. The Kenyan Plant Conservation Program. Unpublished paper.

Oldfield, S. 1993. International Trade in Aloe. TRAFFIC Bulletin 4(1): 25–32.
Robertson, S. A. and Luke, W. R. O. 1993. Kenya Coast Forest Status, Conservation and Management, Report of the National Museums of Kenya/World Wide Fund for Nature (WWF). WWF Project No. 3256.
Wass, P. 1995. Kenya's Indigenous Forest: Status, Management and Conservation. IUCN, Gland, Switzerland, and Cambridge, UK.
WCMC. 1988. Kenya: Conservation of Biological Diversity. World Conservation Monitoring Center, Cambridge, UK.

CONSERVATION OF AGRO-BIODIVERSITY IN TANZANIA

W. Y. F. Marandu and M. J. Nkya
National Plant Genetic Resources Center, P.O. Box 3024
Arusha, Tanzania

SUMMARY

Tanzania is rich in plant diversity with many wild relatives of cultivated crops and others that are important for national food security. Environmental conditions are diverse enough to allow production of a wide range of tropical and sub-tropical crops, however, genetic erosion threatens this diversity.

The National Plant Genetic Resources Center (NPGRC) was established with the broad objective of promoting conservation and sustainable utilization of plant germplasm. The NPGRC has primarily concentrated on agro-biodiversity. The main activities are exploration, collection, storage, documentation, multiplication, characterization, evaluation, and provision of germplasm to users. The NPGRC also coordinates activities related to plant genetic resources in the country.

The NPGRC operates as part of a larger program in the Southern Africa Development Community (SADC) region. Policy issues are handled by a national committee, while scientific and technical activities are handled within the national agricultural research system in collaboration with other institutions.

Acquisition of germplasm is through collection missions, exchange, and deposition by plant breeders. Currently, available germplasm includes crops, forages, multi-purpose species, and wild relatives of crops. Orthodox seeds are conserved at temperatures below -18°C in cabinet freezers equipped with air circulation equipment. The NPGRC also monitors and assists in documentation and maintenance of field gene banks of crops like coffee, cocoa, spices, fruits, roots, and tubers. Major constraints include shortage of staff and equipment due to limited funding. Future plans include building capacity to conserve and enhance germplasm using the most appropriate technologies by integrating *ex situ* methods such as tissue culture, cryopreservation, and *in situ* methods such as farm conservation.

INTRODUCTION

Survival and development of human life greatly depends on existence of plant diversity. Tanzania has a wide range of agro-ecological zones in which more than 120 crops are produced and many more could be grown. Both tropical and sub-tropical crops are grown due to climate modification from sea level to higher altitudes. Most of the crops grown by farmers have wide diversity within them, and farmers have taken advantage of such diversity to develop their own varieties suitable for their environment as well as markets, food preparation methods, etc. The major food and cash crops originated from other places, but most of the minor crops that are responsible for a sustainable supply of food are indigenous or were naturalized a long time ago.

Efforts to conserve plant genetic resources have been made recently as a result of observed and potential genetic erosion in most crops and their wild relatives. In 1986 member-states of the Southern Africa Development Coordination Conference, (currently Southern Africa Development Community, SADC) agreed to establish a

regional gene bank for plant genetic resources. Following this agreement each member state was required to establish a national committee and a national center for plant genetic resources.

Upon recommendation of the International Plant Genetic Resources Institute (IPGRI), the SADC Plant Genetic Resources Center (SPGRC) was established near Lusaka, Zambia, as a project within a genetic resources program of the Southern Africa Center for Cooperation in Agricultural Research (SACCAR). Support for the project was obtained from member-states as well as the Nordic countries (Anon., 1989).

Tanzania formed a national committee for plant genetic resources in 1987, and in 1991 the curator of the National Plant Genetic Resources Center (NPGRC) was appointed to begin activities in Arusha at the Tropical Pesticides Research Institute. The decision to locate the NPGRC in Arusha was made during a national workshop, held in 1990, which involved a wide range of scientists, policy makers, and advisors (Shao et al., 1991).

FUNCTIONS OF THE NATIONAL PLANT GENETIC RESOURCES CENTER

The broad objective of the NPGRC is to promote conservation and sustainable utilization of plant genetic resources in Tanzania. At that time plant genetic resources were considered to be useful plants and plants with potential value including crops and their wild or weedy relatives, genetic stocks, plants with medicinal use, timber species, ornamentals, and any species considered to be endangered or rare.

These objectives can be achieved through:

- exploration and collection of germplasm
- conservation using both *ex situ* and *in situ* techniques
- documentation
- multiplication and rejuvenation
- provision of germplasm and information to users
- germplasm enhancement
- training
- coordination of activities in the country.

It is clear from the broad objective and the definition of plant genetic resources that the NPGRC has a mandate for all plant species in Tanzania. However, as a result of slow development and the limited resources so far available, the NPGRC has concentrated more on agro-biodiversity.

CONSERVATION OF AGRO-BIODIVERSITY

Institutional arrangements

Before the establishment of the National Plant Genetic Resources Center (NPGRC), activities related to conservation of crops were handled by plant breeders in the National Agricultural Research System (NARS) without any obligation as to how long they should maintain such resources. Wild and weedy relatives of crops were rarely considered and *in situ* resources were neither their responsibility nor their concern.

Now, the NPGRC collaborates with plant breeders and other crop scientists to analyze and plan strategies for conservation of individual or groups of crops. Within the Ministry of Agriculture, there are 22 commodity research programs that have regular

coordination meetings. The NPGRC participates in these meetings. The scientists of the NARS also participate in activities of the NPGRC whenever feasible.

Apart from the NARS, there are other institutions that are important in the conservation of agro-biodiversity and from which members of the national committee are often drawn, such as:

1. Tanzania Commission for Science and Technology (COSTECH) is responsible for broad policy development for science and technology, and also issues permits and clearances for research.
2. National Herbarium of Tanzania (NHT) offers identification service, as well as maintains voucher specimens collected by NPGRC and others. Staff of the NHT often participate directly in planning and execution of collection missions particularly when wild and weedy relatives of crops are the target.
3. National Plant Quarantine Station (NPQS) inspects germplasm for export to institutions outside Tanzania as well as imported material to ensure safe movement.
4. Tanzania National Parks (TANAPA) offers the highest level of legal protection to flora and fauna within the parks. National parks have become the first sites to consider when wild relatives of crops have to be collected.
5. National Environmental Management Council (NEMC) is the custodian of the national environmental policy and has one of the largest projects on biodiversity, financed by the Global Environmental Facility.
6. Tanzania Forestry Research Institute (TAFORI) provides information on specific species and *in situ* resources.
7. National universities have a wide range of responsibilities including research, training, and maintenance of herbaria and libraries.

The NPGRC would also be prepared to work with local NGOs though none of the existing ones have shown an interest in the field of plant genetic resources.

Field and laboratory activities

Prior to the establishment of the NPGRC a number of collection missions were conducted by local and international scientists. Most of the collections were sent to international gene banks, and in some cases duplicate samples were left in the country. Many of the duplicates left in the country were eventually lost due to poor, or absence of, storage facilities.

The NPGRC has established storage facilities that allow international gene bank standards to be applied. Any collections made are now maintained at Arusha as active collections, and duplicates are sent to SPGRC for long-term storage. Orthodox seeds are dried to moisture contents between 5 and 7%, depending on the species, and stored in sealed aluminum foil packets at temperatures below -18°C. Provision can be made for other ranges of temperature and moisture content if desired. Cabinet deep freezers equipped with air circulation are used for storage of germplasm.

Acquisition of germplasm is through collection missions, donations, and exchange with other gene banks. So far a number of plant breeders in the country have donated materials for storage while other materials have been collected from farmers and in the wild with the support of relevant scientists.

Since 1991, eight collection missions have been conducted with support from various institutions. Target species were specified for each mission, such as forages (2 missions), chickpeas, oil palm, bambara groundnuts, wild rice, and multi-crop (2 missions).

Currently the NPGRC maintains over 100 species. Crops already collected include maize, beans, finger millet, paddy, groundnuts, cucurbits, bambara groundnuts, sorghum, pearl millet, cowpeas, pigeon peas, lablab beans, chickpeas, and sesame.

Internally, the NPGRC has deliberately paid more attention to the so-called minor crops for which there are no research programs. As a result, the germplasm collections of crops such as finger millet and bambara groundnuts represent the national diversity. Sorghum and beans are also well collected as a result of consolidation of previously collected materials from various institutions.

Normally materials are acquired by the NPGRC in very small quantities. We therefore have a routine multiplication program to provide sufficient seed for duplicate samples as well as for distribution on request. The NPGRC has acquired land for this activity at Tengeru just outside Arusha. The land is already in use, but further developments are needed to allow crops to be grown throughout the year under irrigation. Since the NPGRC maintains a wide range of plant species, the climatic requirements for multiplication can also be very diverse. Ideally, accessions should be multiplied in the same environment as they were collected to avoid genetic drift. Because it is not feasible to send back materials to the areas where they were collected, it becomes necessary to use approximately similar environments as near as possible to the original collection site. Similar fields will be developed in other areas with different climatic conditions as funds are made available. The same fields are used for regenerations when the existing seed stocks have lost viability to an unacceptable level (usually when germination is below 85% of the original level).

Materials in the gene bank are more useful if they are utilized by scientists. However, with large numbers of accessions, bona fide users cannot make their selections with certainty. Therefore, in order to help users to make decisions, the accessions are characterized and where possible evaluated. Since it is not possible to assemble all the expertise on all the species in the gene bank, we usually collaborate with various scientists to accomplish this task. This approach has the advantage of using the skills of specialists as well as allowing the specialists to make their own observations on the available germplasm of a particular crop. By working with crop specialists, the material can be grown at another station where the environment is more suitable for the crop. For example, finger millet accessions have been successfully multiplied in the Southern Highlands under the supervision of a scientist at MARTI Uyole.

Plant species that do not produce orthodox seed (termed recalcitrant), vegetatively propagated crops, and those crops that take many years to produce seed require a different approach for conservation. Crops like coffee, cocoa, bananas, citrus, other fruits, sugarcane, tea, grapes, sisal, cashew, pyrethrum, spices, root crops, and sweet potatoes are maintained in the field. Most of these collections were established by plant breeders at major research stations and are still maintained by them. The NPGRC takes interest in inventory and maintenance of the collection. For example, the coffee collection at Lyamungu is currently being characterized to establish a coffee data base for scientists' use during selection of parental materials. Coffee scientists are working in collaboration with NPGRC scientists to develop this database. Similarly, there has been an effort to consolidate sweet potato germplasm in one field collection to help breeders make direct comparisons as well as reduce the number of small fields scattered throughout the country with insufficient management. The sweet potato collection is now maintained in our field at Tengeru.

Documentation

Information is generated at various steps during acquisition, processing, storage, characterization, and multiplication of germplasm. All important information is stored in a computer. A database program, SADC Documentation and Information System (SDIS), has been developed for documentation of all routine data for all SADC member-states. This program, based on dBase IV, provides the member-states with an opportunity to exchange information on individual accessions. The SPGRC maintains data from its own gene bank as well as from all member-states.

Stored information includes names of collecting teams, passport data, registration at gene bank, germination, storage information, and characterization data. The program further allows recording of information on other activities that are not directly associated with individual accessions such as staff information, equipment, working groups, committee members, and scientific names of crops known in the SADC region.

Each SADC member-state maintains its own database and regularly updates the SPGRC by transfer of information on diskettes. Data summaries about each accession can be prepared using SDIS to be viewed on the screen or stored on diskettes to be printed later.

AVAILABILITY OF GERMPLASM

Germplasm stored by the NPGRC is available for use by users within and outside the country. Duplicate samples stored by SPGRC are not for distribution. In accordance to Article 15(1) and (4) of the Convention on Biological Diversity, access to germplasm is subject to national legislation and granted on mutually agreed terms (Anon., 1992); therefore, these samples are maintained on a long-term basis as a backup to the national programs. Requests sent to the SPGRC are channeled to the individual countries and handled like any other request.

Tanzania is a member of the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) and adheres to the International Undertaking for Plant Genetic Resources (which is under revision). Conditions of access to crop germplasm are set and revised on the basis of guidelines or agreements reached by members of the CGRFA. Non-members of the CGRFA and those who do not adhere to the International Undertaking for Plant Genetic Resources may be given additional conditions where relevant in accordance with articles of the Convention on Biological Diversity.

TRAINING

Training of personnel has been an important component of the SADC genetic resources program. The NPGRC assumed a coordinating role for training in issues relating to plant genetic resources locally. Various short and long courses are available outside Tanzania, the most important being the M. Sc. program for Conservation and Utilization of Plant Genetic Resources offered by the University of Birmingham in the United Kingdom and special short course for SADC jointly offered by the Danish Royal Veterinary and Agricultural University, Copenhagen, and the Nordic Gene Bank. There have been other short courses organized by various institutions including IPGRI, ILCA (now ILRI) IITA, and SPGRC. Participants for these courses have been drawn from the NPGRC and research institutes under the Ministry of Agriculture, TAFORI, and the National Herbarium of Tanzania. Because issues of plant genetic resources are

numerous and complex we believe that by training as many people as possible from diverse scientific disciplines and institutions, there will be a general awareness of the importance of conservation of germplasm in Tanzania.

INTERNATIONAL COLLABORATION

Tanzania has been open to international collaboration on issues of plant genetic resources conservation. The International Agricultural Research Center (IARC) of the Consultative Group on International Agricultural Research has been working in collaboration with local research institutes for a long period. The IARC has a mandate for a limited number of crops, but it has been instrumental in encouraging plant breeders to use diverse germplasm. Some of the IARC (ICRISAT, IITA, and IRRI) have made several collection missions in Tanzania. Accessions of sorghum and finger millet collected by ICRISAT in Tanzania have been made available to NPGRC through SPGRC for maintenance in the active collection.

IRRI is currently collaborating with SPGRC to collect wild rice in Tanzania and other SADC member-states. The NPGRC collaborates with IPGRI in many activities including technical advice and support, training, participation in collection missions, documentation of plant genetic resources, and training. IPGRI is also an important source of literature on plant genetic resources.

Many other international institutions are accessible to the NPGRC for their specialized services including the Nordic Gene Bank (consultants to the SADC program); the Royal Botanical Gardens in Kew (maintaining most wild materials collected by IPGRI collectors); the International Center for Under-utilized Crops (promoting the Southern and Eastern Africa Network for Under-utilized Crops for which the NPGRC is the local coordinator), and FAO (as an inter-governmental forum for the handling global policy issues on agro-biodiversity).

CONSTRAINTS

The NPGRC is faced with a number of constraints that limit its capability to conserve plant genetic resources, including lack of human resources, equipment, operating funds, and an unclear definition of its mandate in its relationship with other institutions that have a role in plant conservation. These constraints are being addressed by the government, but without a long-term investment plan, its progress will be very slow.

FUTURE ACTIVITIES

The most important activity in the near future is to build capacity for NPGRC and other institutions in the country to conserve germplasm efficiently. To do so, the most appropriate technologies must be applied in all stages of conservation. There is need to integrate *ex situ* conservation with *in situ* conservation. *Ex situ* conservation can be improved in some cases by applying *in vitro* culture or other biotechnologies, while *in situ* conservation can be enhanced by involving farmers in the maintenance and sustainable use of their own crop varieties.

Genetic enhancement of germplasm may be required in some crops in order to attract plant breeders to exploit the available diversity more frequently. To achieve this goal, it will be necessary to use specialists in various fields, particularly in gene transfer technology, cytogenetics, and other related fields.

Finally, conservation of agro-biodiversity in Tanzania will be a success only if a mechanism is in place to allow information to flow between individuals and institutions. Efforts will have to be made to promote networking and public awareness of conservation and sustainable use of available germplasm.

CONCLUSIONS

Tanzania is rich in agro-biodiversity, particularly crops and their wild or weedy relatives. The National Plant Genetic Resources Center plays a major role of conservation and coordination of activities related to crop germplasm. Conservation and sustainable use of agro-biodiversity requires serious investment in human resources, equipment, and institutional setup.

REFERENCES

Anonymous. 1989. A Regional Plant Genetic Resources Center, SADCC: Plan of Operation 1989–1992. SADCC Member States and Nordic Countries. SIDA, Stockholm.

Anonymous. 1992. Convention of Biological Diversity. UNEP.

Shao, F. M., Magingo, F. S. S., Minjas, A. N., Bitanyi, H. F. and Mahunnah, R. L. 1991. Plant Genetic Resources and Biotechnology. Proceeding of the 1st National Workshop, Arusha, Tanzania; 16–20 January, 1990. Benedictine Publications Ndanda, Peramiho, Tanzania.

PROTECTED AREAS AND PLANT CONSERVATION IN TANZANIA: AN APPRAISAL

William R. Mziray
National Herbarium of Tanzania
P.O. Box 3024, Arusha, Tanzania

SUMMARY

The idea of protecting designated areas and biological species from human activities or exploitation in Tanzania is not new. Such efforts started back in the colonial days for various reasons. The national governments have maintained the practice and added more areas for protection. Most of the protected areas have been established, controlled, and managed through five major legislations, all aimed at protecting vegetation and wildlife (animals) in Forest Reserves (FR), National Parks (NP), Game Reserves (GR), Game Controlled Areas (GCA), a Conservation Area (CA) and a Nature Reserve (NR). It is observed that there are control and management problems that are, nevertheless, being alleviated through provisions to amend the legislations whenever deemed necessary for more effective protection. It is further noted that with the advent of the Convention on Biological Diversity (CBD), more players have joined the struggle to create increased public and institutional awareness on the need to conserve biodiversity and to plan and support various conservation strategies. It is concluded that although there are a number of areas that need to be urgently addressed for the improvement of plant conservation in the country, Tanzania's performance in this noble task is satisfactory and promising.

INTRODUCTION

The flora of Tanzania is indisputably very rich, in species number and genetic diversity. It has been estimated that vascular plants alone represent around 10,000 species (Polhill, 1968), about 10% of which are believed to be endemic (Brenan, 1978) not including the relatively lesser-known lower plants, such as algae, bryophytes, lichens, and fungi. This richness in plant genetic resources may be attributed to the fact that the country is relatively large (ca. 942,800 km^2), with diverse ecological environments. This has allowed the establishment of various vegetation types including afro-alpine flora, mist and dry montane and sub-montane forests, groundwater forests, swamp forest, woodlands, savanna grasslands, thickets, bushland, lowland coastal and inland mosaic forests, mangroves, and salt marshes, occurring from an altitude of about 4500 meters down to sea level.

As a result of the ever-increasing human population and the adoption of modern standards of living, excessive demands are being put on the country's existing biological resources, leading to their overexploitation without equivalent efforts to replace them. Plants from the wild are exploited as sources of food, medicine, and construction materials and as raw materials for various industrial processes. Uncontrolled cultivation of food and cash crops, the process of urbanization, and related infrastructural developments all lead to the clearing of vegetation consisting of actually or potentially useful plant species. Moreover, Tanzania has opened the gates to increased tourism as well as scientific and amateur explorations.

The obvious outcome of these diverse human activities is that plant genetic resources are being depleted faster than the natural replenishment rate. Some plant species become extinct even before they are scientifically documented. Indeed, environmental deterioration is no longer difficult to appreciate; signs that biological diversity is undergoing destruction are very prominent. As such, Tanzania, like many other countries, is making conscious efforts to ensure that legislation governing protected areas is not contravened and that more sites worth protecting for conservation purposes become designated and mapped quickly.

HISTORICAL PERSPECTIVE

Traditionally, some areas set aside either as places of worship or for ceremonial rituals were subjected to minimal human activity, thereby protecting biological resources occurring within them. During the colonial days in the earlier part of this century, laws had been enacted to protect selected areas for various objectives, such as water catchment or aesthetic values. Thus, the idea of protecting designated areas from human activities in Tanzania is not new. Both the Forest Ordinance and the Ngorongoro Conservation Area Ordinance were already in place in 1959 to protect game and forests, respectively. Even the idea of protecting particular species of organisms from overexploitation has been in practice for a long time. Ever since colonial times, for example, it has been unlawful to harvest the plant species *Milicia* (Chlorophora) *excelsa* or hunt giraffe without a special permit. As a result of protecting particular sites for various reasons, a range of organisms within them have become automatically conserved *in situ*, whether deemed endangered or otherwise.

PROTECTED AREAS

The major protected areas in Tanzania are aimed at protecting vegetation and wildlife (animals) in the form of Forest Reserves (FR), National Parks (NP), Game Reserves (GR), Game Controlled Areas (GCA), a Conservation Area (CA), and a Nature Reserve (NR). Table 1 lists the regions where FR of Tanzania are located, the number of reserves, and total area (ha).

Table 1. Summary of forest-protected areas in Tanzania (the full listing is available from the author). T. T. = Tanganyika Territory, L. A. = Local Authority.

Region	#	Type reserve	Total area (ha)	#	Type reserve	Total area (ha)
Arusha	27	T. T	271,575			
Dodoma	13	T. T.	134,804	8	L. A.	55,980
Iringa	38	T. T.	332,775	30	L. A.	142,252
Kagera	15	T. T.	307,487	1	L. A.	2,522
Kigoma	14	T. T.	1,528,787	9	L. A.	119,558
Kilimanjaro	20	T. T.	138,043	9	L. A.	5,469
Lindi	27	T. T.	558,669	4	L. A.	4,076
Mara	2	T. T.	2,940	5	L. A.	1,733
Mbeya	27	T. T.	439,608	30	L. A.	100,603
Morogoro	84	T. T.	1,261,121	10	L. A.	7,341
Mtwara	9	T. T.	58,850	8	L. A.	8,545
Mwanza	19	T. T.	133,164	20	L. A.	37,303
Pwani	46	T. T.	213,249	2	L. A.	90,599

Table 1. (continued).

Region	#	Type reserve	Total area (ha)	#	Type reserve	Total area (ha)
Rukwa	16	T. T.	2,628,931	3	T. T.	181,680
Ruvuma	11	T. T.	638,391	2	L. A.	191
Shinyanga	12	T. T.	579,973	25	L. A.	232,168
Singida	1	T. T.	785,263			
Tabora	33	T. T.	3,257,943	8	L. A.	730,074
Tanga	87	T. T.	142,712	19	L. A.	10,410

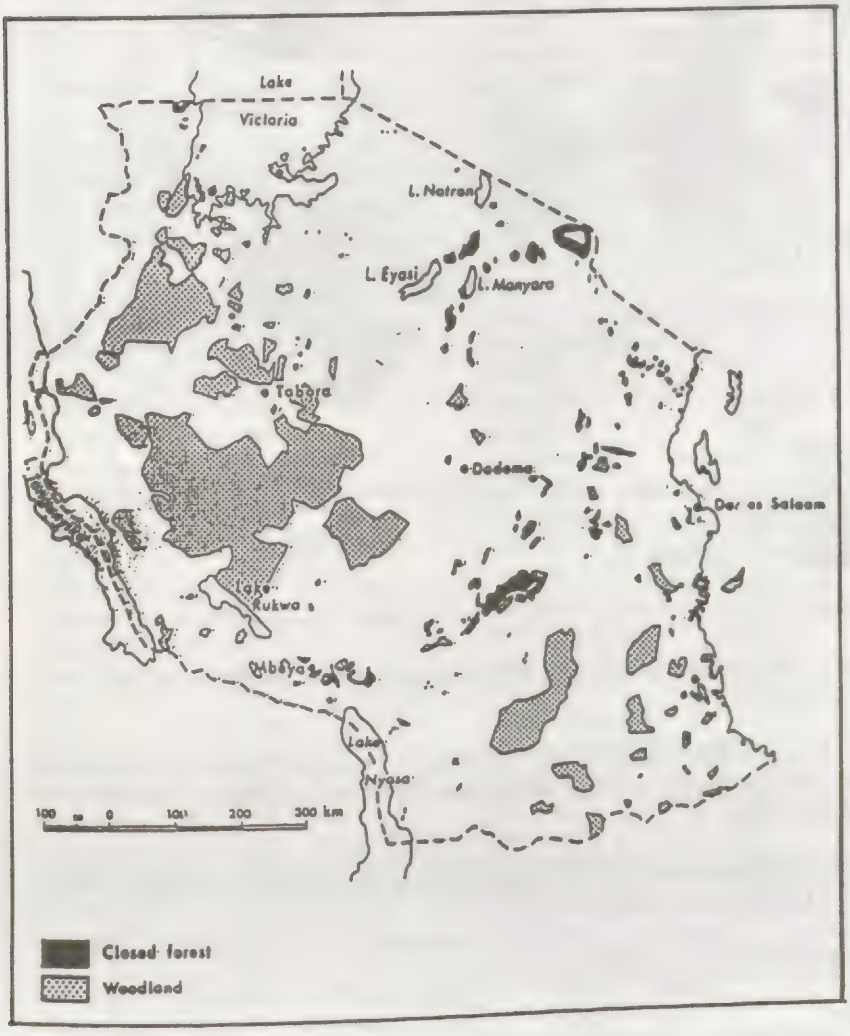


Figure 1. General geographical locations of both closed forest and woodlands in Tanzania.

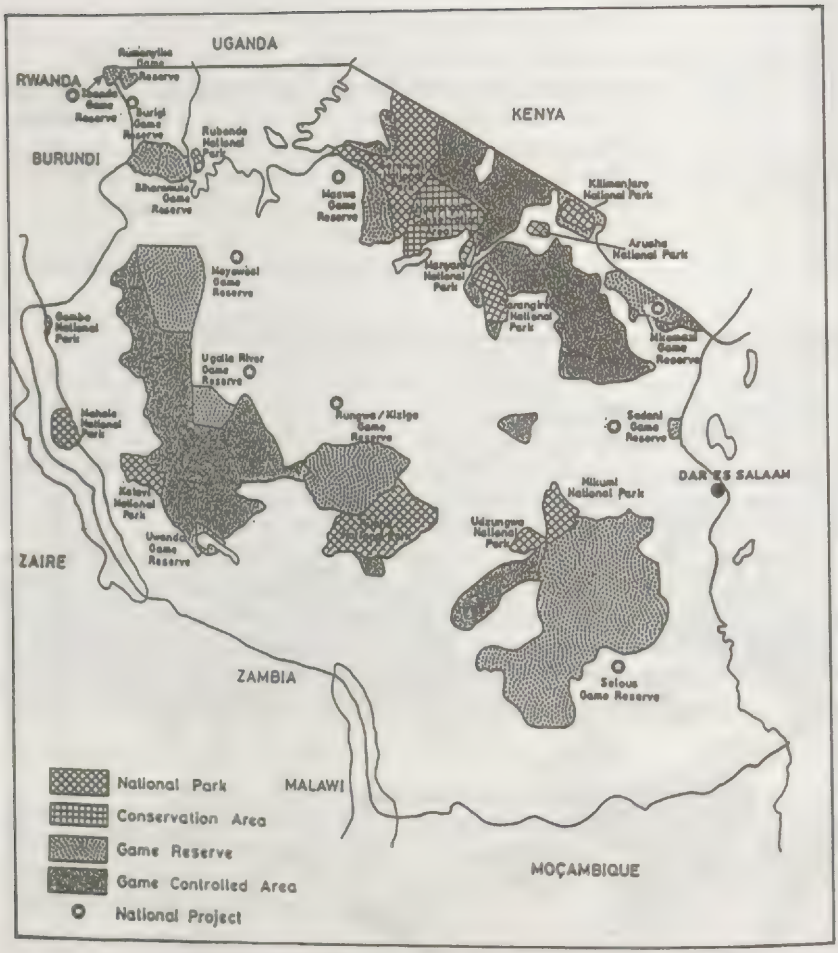


Figure 2. The locations of major wildlife protected areas in Tanzania (from Tanzanian Wildlife Division, 1991).

There are numerous game-protected areas in Tanzania. These are listed in Table 2 along with the area and year of establishment. There are many game-controlled areas in Tanzania (Table 3).

Table 2. Game-protected areas in Tanzania. GR = game reserve, NP = national park, CA = conservation area.

Location	Area (ha)	Year est.	Location	Area (ha)	Year est.
Ownership: Directorate of Wildlife (GR)					
Selous	50,000	1922	Mkomazi	1,000	1951
Rungwa	9,000	1951	Mt. Meru	300	1953
Kilimanjaro	900	1956	Biharamulo	1,300	1959
Maswa	2,200	1962	Ugalla	5,000	1965

Table 2. (continued).

Location	Area (ha)	Year est.	Location	Area (ha)	Year est.
Ownership: Directorate of Wildlife (GR)					
Saadani	300	1968	Uwanda	5,000	1971
Burigi	2,200	1972	Ibanda	200	1974
Umba	1,500	1974	Rumanyika	800	1974
Moyowosi	6,000	1981	Kizigo	4,000	1970/82
Kigosi	7,000	1983	Saa Nane	0.5	1994
Grumeti	2,000	1994	Ikorongo	3,000	1994
Kijereshi	300	1994	Muhesi	2,000	1994
Ownership: Tanzania National Parks Authority (NP)					
Serengeti	14,763	1951	Lake Manyara	330	1960
Mikumi	3,230	1964	Arusha	137	1960
Ruaha	10,380	1964	Tarangire	2,600	1970
Kilimanjaro	756	1973	Mahale Mts	1,577	1980
Rubondo Is.	450	1977	Katavi	2,253	1974
Gombe Stream	52	1968	Udzungwa	1,900	1992
Ownership: Ngorongoro Conservation Area (CA)					
Ngorongoro	8,300	1951			

Table 3. Game-controlled areas (GCA) in Tanzania

Name	Area (ha)	Name	Area (ha)
Burunge	400	Chabula Marsh	100
Gombe	3,000	Handeri	3,000
Igombe Dam	3,500	Kalimawe	300
Kihurumira Pool	100	Kilombero	6,500
Kitwai	3,500	Kongwa	1,500
Lake Daramatai	0.02	Lake Kwela	70
Lake Marika	20	Lake Natron	3,000
Lihogosa	30	Loliondo	4,000
Lolkisale	1,500	Longido	1,500
Luganzo	2,500	Lukwati	2,000
Lunda Mkwambi	1,000	Makao	1,000
Masasi River	180	Meserani Dam	75
Mkungunero	700	Mlele	3,000
Msima	2,000	Mto-wa-Mbu	1,500
Muhuwesi	1,500	Mwadui Diamond Mines	10
Mwambesi	1,000	Nchwa-Nkima	50
Ngeju Njiro Dam	30	Nyonga	3,500
Rau Forest	100	Rukwa	400
Rungwa River	1,500	Ruvu Maasai	1,500
Ruvu Same	1,000	Sanya Lelatema	800
Simanjiro	2,000	Ugunda	1,500
Umba River	300	Utengule Swamps	500

The objectives for protection differ depending on the category to which the area belongs. Forest Reserves are classified in two groups, on the basis of their differing management goals. Productive FRs consist of exploitable forests maintained purely for

the production of timber and other useful forest products. Protective FRs, on the other hand, comprise forests reserved because of the importance of their biological resources or for catchment purposes. According to the Tanzania Forestry Action Plan (TFAP) that is currently in use, some 44.3 million ha of land, nearly half of the total area of Tanzania (Mainland), are classified as being forested. However, only about 13 million ha are protected through approximately 540 FRs.

National Parks, on the other hand, are selected on the basis of outstanding natural, archaeological, cultural, and ecological merits. They are created to conserve biological resources within them primarily for recreational, educational, cultural, and scientific purposes. They are open to tourists under rather strict conditions. Game Reserves have a lesser protection status with the primary objective of protecting game under controlled forms of sustainable wildlife utilization. Game Controlled Areas are comparatively less restricted, acting as the basis for upgrading the conservation status of an area as may be deemed fit. Partial Game Reserves are protected to conserve specific groups of organisms. Igombe Dam has been cited as a good example; it serves as a sanctuary for several species of birds.

Apart from its greatly valued wildlife, aesthetic, catchment, archaeological, and cultural attributes, the Ngorongoro Conservation Area is also inhabited by a significant population of Maasai pastoralists and their livestock. As such, NCA is managed as "a multiple land-use area that aims to integrate the conservation of its varied natural values with the interests of the resident Maasai pastoralists and their livestock." (Anon., 1996).

LEGISLATION

The protected areas of Tanzania are governed by five major pieces of legislation, namely:

1. The Forest Ordinance, Cap. 389 of 1959
2. The Wildlife Conservation Act, No. 12, of 1974
3. The National Parks Ordinance, Cap. 412 of 1959
4. The Ngorongoro Conservation Area Ordinance, Cap. 413 of 1959 and
5. The Amani Nature Reserve Declaration Order, Government Notice No. 152 of 1997.

The Forest Ordinance of 1959 provides that all Forest Reserves are declared by the relevant Minister and are gazetted under this legislation. Generally, protective FRs are restricted from public exploitation, except under specially authorized circumstances that ensure that the basic protection objectives are not contravened. This ordinance also allows for the establishment of other categories of protected areas in unreserved public lands that may be managed by local or central government authorities.

The Wildlife Conservation Act (WCA) of 1974 is accompanied by two principal supplements: the Wildlife Conservation (Game Controlled Areas) Order, 1974, and the Wildlife Conservation (Game Reserves) Order, 1974. These clearly accommodate Game Controlled Areas (GCAs) and Game Reserves (GRs), respectively. It has been emphasized that during implementation of the WCA, the other three (first, third, and fourth) legislations are also recognized and respected for harmonized action. Expectedly, these Orders are modified from time to time to take care of newly gazetted protected areas or as the status of a protected area changes. Apart from the two categories of areas protected under this Act, there is also a third, less common one known as Partial Game Reserves, for which it has been suggested that no specific legislation exists, although the process to formulate one was in progress.

Under the WCA of 1974, Game Reserves that are declared by the President have higher conservation status than GCAs; permanent human habitation, agriculture, livestock grazing, and mineral prospecting or exploitation are strictly prohibited in them while controlled forms of sustainable wildlife utilization may be permitted by the director of wildlife. Game-controlled areas are comparatively less restricted, and they act as the basis for upgrading the conservation status of an area as may be deemed appropriate. Partial Game Reserves, on the other hand, are protected to conserve specific groups of organisms and can be declared by the director of wildlife. Igombe Dam, which has been cited as a good example, serves as a sanctuary for several species of birds.

The National Parks Ordinance is used to manage national parks, which are normally declared by an Act of Parliament. Strictly non-consumptive recreational activities and those necessary for the effective management and development of the area are allowed here. National parks are said to be accorded the highest protection status, although they are open to tourism.

The Ngorongoro Conservation Area Ordinance, also enacted by Parliament, concerns the establishment of the Ngorongoro Conservation Area Authority and management of the Ngorongoro Conservation Area. The area is unique in that it is the only protected area where indigenous human habitation is legally permitted.

The Amani Nature Reserve Declaration Order has introduced a new chapter in the history of plant conservation in Tanzania. Although the concept of a Nature Reserve (NR) as an area protected to specifically conserve the contained biological resources had been lingering around, there had been no legal support for areas designated as such until earlier this year when the Amani Nature Reserve was gazetted, "...for the protection of the biodiversity and endemic plants and animals of these sub-montane forests" (Anon., 1997). Prior to this, only two areas were designated, unofficially, as nature reserves: a small portion of the Shume-Magamba Forest Reserve in the west Usambara mountains and the Luyisenga NR within the Mufindi Tea Estates, both of which are yet to be mapped.

Other specialized legislation has an impact on the environment and, hence, plant conservation. These include the Fisheries Conservation Act of 1970, the Plant Protection Ordinance, the Soil Conservation Ordinance, the Water Conservation Ordinance, the Grass Fires (Control) Ordinance, the Cattle Grazing Ordinance, and the Marine National Park Act (under proposition). These and several other legislations are discussed in detail by Hitchcock (1994). Additionally, there are by-laws that are also used to protect particular areas for specific purposes, such as water catchment or ceremonial rituals, at the local authorities level. Whatever the main objective of the legislation, plants and other biological resources that happen to occur within the area in question often become automatically protected from excessive human exploitation.

Incidentally, it should be pointed out that authorities for areas protected to principally save wildlife are also equally concerned about the safety of plants in their areas since they form the basis for animal survival, while such concern may not necessarily be conversely shared by forest authorities.

In spite of these laws there have been many control and management problems in these protected areas. Encroachment is commonplace and resources to ensure effective law enforcement are inadequate, making it difficult to apprehend culprits and bring them to justice. On the other hand, there are provisions to amend the legislation

as circumstances may dictate for the purpose of ensuring effective protection. Regardless of the shortcomings, a considerable level of protection has been achieved, thanks to the existence of a legal protection framework.

MANAGEMENT STATUS

Nearly all the protected areas in Tanzania are publicly owned, with the exception of relatively small patches of land that may be privately owned, either by traditional or religious groups or by precious few individuals. The different public authorities involved in managing protected areas include:

1. Tanzania National Parks (TANAPA), responsible for the 12 National Parks (Table 2)
2. Ngorongoro Conservation Area Authority, responsible for Ngorongoro Conservation Area only
3. Director of Wildlife, responsible for specified Game Reserves treated as National Projects, currently only eight (Figure 2)
4. Regional authorities, responsible for relevant protected areas that fall within their borders and mandates
5. District authorities, responsible for some specified Forest Reserves within their boundaries

I have not been able to establish who has the responsibility for the newly gazetted Amani Nature Reserve. However, I do know that at present the reserve is under the stewardship of the East Usambara Catchment Forest Project, presumably on behalf of the Tanzania Forestry Research Institute (TAFORI).

INVASION BY INTRODUCED PLANTS

Colleagues of mine (Abdallah and Black, p. 223) have presented a report on "Safe movement of germplasm between countries" from a quarantine point of view. This aspect certainly needs to be seriously considered in relation to *in situ* conservation. The introduction of foreign plant species to a new place can seriously jeopardize efforts to save indigenous species. In Tanzania, for instance, the introduction of *Maesopsis eminii* to the East Usambaras for forestry reasons in 1913 has had serious repercussions to the survival of some of the native tree species and is said to degrade catchment quality. Binggeli and Hamilton (1990) have documented seven impacts of *Maesopsis eminii* to the forest ecosystem composition and structure in the Kwamkoro and Amani areas.

Another outcry yet to be investigated is the invasion of a national park in western Tanzania by the introduced ornamental species, *Senna spectabilis*. The Tanzania National Park authorities have indicated that this plant tends to displace certain indigenous plant species, some of which are favorite food for primates. Evidently, the introduction of plant species to new areas, even if it amounted to transfer from one corner of the country to another, should be treated with considerable caution, for effective conservation efforts.

PLANT INVENTORIES

One aspect that has so far received relatively little attention is the production of checklists of the biological resources within protected areas. Attempts to retrieve any available plant checklists have indicated that relatively few exist, and most of them are still far from complete or relatively old. On the other hand, there are encouraging signs that, with the advent of the global biodiversity conservation initiative following the Convention on Biological Diversity that Tanzania has already ratified, the need to take inventory of biological resources in priority areas is becoming better appreciated. As a result, most biodiversity-oriented projects currently under implementation include species inventories of the organisms of interest in the relevant areas (Lovett and Pocs, 1993; Anon., 1991).

Meanwhile, the National Herbarium of Tanzania (NHT), with the mandate to catalogue the entire national flora, is trying to double its efforts to attain that goal in the shortest possible time. One strategy that emanated from a conference involving the major botanical institutions in the country, in 1993, aims at producing local collectors (or parataxonomists) who would be attached to ongoing, long-term conservation-oriented projects around the country to facilitate plant inventorying as they go about their normal duties. At the same time, technical staff in the major herbaria and other relevant institutions with a botanical component would be trained in modern herbarium techniques to help them cope with more intense plant collecting and a greater influx of herbarium specimens. That strategy led to the formulation of a training program (Tanzania Botanical Training Program) through the joint efforts of the Missouri Botanical Garden (MBG) and the NHT, which has already been co-funded by the MacArthur and the Claiborne-Ortenberg foundations. Indeed, as we meet here, the local collector who is part of the training program is heading back home. This program, we hope, will go a long way in building the much-needed capacity of our botanical institutions, both in terms of personnel and equipment.

MAPS

It has been shown that no legally protected area lacks a map showing its limits, administrative location, and its estimated size, because this was a prerequisite for mapping. Such a map is usually accompanied by a descriptive statement of the relevant details, including the objective for protection. These maps may be supplied on request from the relevant authorities. In addition, it has been revealed that general management plans had been prepared for some of the protected areas, e.g., the Selous Game Reserve and the Mangrove Ecosystem of Mainland Tanzania; others were in the process of preparation. Such plans should give details of the proposed management strategies as well as different maps showing details of various aspects.

Moreover, overall country maps exist, showing all major protected areas (Figures 1 and 2). The currently used combined overall map, however, is already outdated; plans to update it are said to be under way. Meanwhile, an up-to-date map, at a scale of 1:250,000, comprising 54 different pieces for the entire country and giving details of land cover and land use, has been produced, though not yet officially released. This is a product of the Ministry of Tourism in the Natural Resources and Environment, through Hunting Technical Services (UK) and the Institute of Resource Assessment as Technical Consultants and Local Supervisors, respectively.

INFORMATION SOURCES

Apart from the Ministry of Tourism in the Natural Resources and Environment, other important sources of information on protected areas have also been identified. These include: Environmental Information Center of the National Environment Management Council (NEMC) in Dar es Salaam; Tanzania Natural Resources Information Center at the Institute of Resource Assessment (IRA), University of Dar es Salaam; and regional and district natural resources authorities.

DISCUSSION

It has become evident from my investigations that several earlier records on protected areas in Tanzania were incomplete. Some reports give more emphasis to areas devoted to game protection (IUCN, 1987; Sayer et al., 1992), while others are biased toward areas committed to the preservation of forests (Polhill, 1968). Indeed, the title of Sayer et al. (1992) reads "The Conservation Atlas of Tropical Forests," and yet the information furnished, at least for Eastern Africa, is on game-protected areas and not forests! It should be further noted that the different lists encountered in the literature, especially those of FRs, are inconsistent and, unfortunately, the most up-to-date version from the Directorate of Forestry could not be availed even though it is said to exist. This investigation has, nevertheless, gone a step further in attempting to bridge the gaps by pooling together as much information as could be obtained on as many protected areas as possible. Admittedly, even this report cannot claim to be exhaustive or even totally accurate; some refinements are still necessary. For instance, information on protected areas covered by legislation mentioned above, which also has a bearing on plant conservation, is not included here.

Furthermore, other areas are protected through local government by-laws, which become effective even before the process of having the areas mapped and declared by the appropriate national authorities is completed. Additionally, some areas are protected for traditional or religious rituals, in the course of which they also serve to protect biological resources. Although such sites may not be very significant in terms of area coverage, they should by no means be ignored, since they may, in fact, be harboring plant genetic resources of special importance, actual or potential. It will evidently take quite some time before all such areas are identified and documented accurately in a country like Tanzania, but efforts in that direction should be made. Of course, protection of areas for conservation or otherwise is a dynamic process; there is need to periodically update available information.

The extent to which legally protected areas are successfully managed without illegal encroachment is a matter of concern. One frequently hears complaints about illegal activities in protected areas, usually by the neighboring communities. While policing by state organizations may help, they have a lot of limitations, ranging from inadequate facilities to gross irresponsibility. Hitchcock (1994) attempts to analyze existing legislations pertaining to the environment in relation to their successes and failures. A generally accepted shortfall relates to ignorance as well as conflicts of interest between local communities and management authorities. One approach now being tried in Tanzania is a community-based conservation strategy, which attempts to educate communities on the values of protecting their neighborhoods while at the same time ensuring that they, too, share the benefits of protecting the area in question. A number of NGOs are actively popularizing this approach, such as the Tanzania Wildlife

Conservation Society, the Malihai Clubs of Tanzania, the African Wildlife Foundation, and the Community Conservation Service Center. The Directorate of Wildlife also has a section that attempts to adopt this strategy.

It has been suggested by wildlife personnel (pers. comm.) that protected areas under their management are better protected because they have concern for both animals and plants, while foresters cared mostly for forest plants. This may be a valid point; authorities responsible for forest protection should be urged to reciprocate by paying reasonable attention to animals within their areas.

These problems notwithstanding, the authorities responsible for the various protected areas should ensure that they are minimally encroached to achieve the highest possible level of protection, pending the completion of botanical inventories that would facilitate the identification of those species that need special conservation attention. Maximum success in these efforts require the enlistment of support from the government, relevant law-enforcement organs, conservation-oriented NGOs, the donor community, and, above all, the local surrounding communities.

Tanzania's ratification of the Convention on Biological Diversity and the ever-increasing awareness of the need to conserve biological resources, makes it imperative to urgently take stock of our indigenous flora and assess the vulnerability status of each species for their possible conservation *in situ* or as may otherwise be appropriate. Botanists have a special role to play, not only with regard to floral inventories, but also in the area of taxonomic research to elucidate inter-specific relationships, document undescribed species, and advise legislators accordingly in relation to conservation options. It is encouraging that some positive action is already under way. The major constraint here is the inadequacy of local taxonomic personnel to carry out plant inventory work. However, if continued, the training initiative already undertaken by MBG and NHT may alleviate the problem significantly.

A final concern that is becoming increasingly important in Tanzania today is the influx of seemingly unscrupulous individuals who have been immigrating with a whole range of ulterior motives, following the recently introduced open market policy and softer passage regulations. Many of these people take advantage of loopholes in the legal system as well as a number of implementation weaknesses, ranging from inadequacy of monitoring facilities to corruptive tendencies. Their entry status may differ widely, and they may or may not possess valid permits. While fulfilling or appearing to fulfill their declared missions, they take advantage of circumstances to enter and do a little mischief in protected areas. Examples of undesirable actions include unauthorized introduction of exotic plant species for growing, harvesting plant material of endangered species, illegal exportation of prohibited plant genetic resources, and the like. The endemic genus, *Saintpaulia*, which occurs only in some of the eastern-arc mountains and neighboring coastal lowlands of Tanzania and Kenya (Lovett, 1989), is one of the most targeted endangered genera along with several species of orchids and aloes, and, as you may know, it is very easy to smuggle out. In this connection, an appeal is made to all those who are inclined to fall prey to this environmentally unfriendly practice to adhere to relevant regulations and proper ethics. At the same time that the government is urged to be more alert in stopping these practices, all other stakeholders and conservation enthusiasts should play their respective roles effectively.

CONCLUSIONS

The present investigation has clearly demonstrated that there are substantial areas in Tanzania that have been set aside for protection with different objectives. Fortunately, some areas are already being protected to conserve biological resources *in situ*. Generally, it is observed that whatever the objective for protecting pieces of the environment, the net result is to conserve plants as well as other biological resources within them. However, efforts to take inventory of existing plant genetic resources should be intensified so we may know exactly what we are conserving and also use such data to guide conservation decisions.

ACKNOWLEDGMENTS

I wish to thank the director of the Tropical Pesticides Research Institute for permitting me to attend this meeting and the sponsors of this 3rd DNA Bank-Net meeting for allowing me to participate. To the NHT staff, Mary and Neduvoto, I am thankful for their assistance with figure preparation. I am especially grateful to Ms. Odilia Shirima who painstakingly typed the long tables of protected areas. Finally, I feel obliged to the various people who willingly provided me with the information I needed to compile this paper.

REFERENCES

Anonymous. 1987. IUCN Directory of Afrotropical Protected Areas. IUCN, Gland Switzerland and Cambridge, UK.

Anonymous. 1989 Tanzania Forestry Action Plan. Ministry of Natural Resources and Tourism (Division of Forestry), Dar es Salaam, Tanzania.

Anonymous. 1991. Management Plan for the Mangrove Ecosystem of Mainland Tanzania. Vol. 1: Mangrove Management Plan for the Tanga and Muheza Districts. Ministry of Tourism, Natural Resources and Environment (Catchment Forestry Project, Directorate of Forestry and Bee-keeping), Dar es Salaam, Tanzania.

Anonymous. 1996. Policy for Wildlife Conservation Ministry of Tourism, Natural Resources and Environment. Directorate of Wildlife, Dar es Salaam, Tanzania.

Anonymous. 1997. Gazette of the United Republic of Tanzania. No. 19, Vol. 78, as Government Notice No. 151 (Rules) and 152 (Declaration Order).

Binggeli, P. and Hamilton, A. C. 1990. Tree Species Invasions and Sustainable Forestry in the East Usambaras. *In*: Research for Conservation of Tanzania Catchment Forests, I. Hedberg and E. Persson, eds. Workshop Proceedings, March, Sokoine University of Agriculture, Morogoro, Tanzania.

Brenan, J. P. M. 1978. Some aspects of the phytogeography of Tropical Africa. Annals of the Missouri Botanical Garden 65: 237–78.

Hitchcock, L. 1994. Report on Existing Legislation Pertaining to Environment. Ministry of Tourism, Natural Resources and Environment (Directorate of Environment), Dar es Salaam, Tanzania.

Lovett, J. C. 1989. Feeling forests. Swara Magazine 12(6): 28–30.

Lovett, J. C. and Pocs, T. 1993. Assessment of the Condition of the Catchment Forest Reserves, a Botanical Appraisal. (Catchment Forestry Project, Directorate of Forestry and Bee-keeping), Dar es Salaam.

Polhill, R. M. 1968. Tanzania. *In*: Conservation of Vegetation in Africa South of the Sahara, I. Hedberg and O. Hedberg, eds. Almqvist and Wiksell, Uppsala.

Sayer, J. A., Harcourt, C. S. and Collins, N. M. 1992. The Conservation Atlas of Tropical Forests: Africa. Macmillan, Basingstoke, UK.

GERMPLASM COLLECTION AND CONSERVATION IN UGANDA: PROSPECTS AND CONSTRAINTS

Remigius Bukenya-Ziraba
Department of Botany, Makerere University
P.O. Box 7062, Kampala, Uganda

SUMMARY

Uganda is a small country (236,578 km^2). Despite its small size, it has a diversity of species and habitats. It is at the junction of five biogeographic regions. These include the predominantly Lake Victoria mosaic in the south, the Sudanian in the north, the Somali-Turkana in the extreme northeast, the Guinea-Congolian south of Lake Albert, and the Afromontane in the mountains. In terms of numbers of biogeographic regions, Uganda possesses the highest diversity on the African continent.

Recent estimates suggest that more than 5000 species of vascular plants occur in Uganda. Uganda's forests support about 50% as many species as the richest-known African sites. The relatively large forests are protected by government as forest reserves. Smaller forest remnants, shrubs, and lianas that are not contiguous forest systems are not protected, and are therefore vulnerable to degradation through agricultural practices.

Uganda is predominantly an agricultural country, with 83% of its labor force engaged in agriculture. Agriculture, especially the cultivation of commercial crops and modern crop varieties, has resulted in extensive clearing of forests, leaving little closed-canopy forest outside of government forest-protected areas. Other habitats have also greatly suffered from human activities. There is an urgent need to collect and conserve as much germplasm as possible in order to arrest genetic erosion and to ensure the availability of the present resources for future generations.

In Uganda, germplasm collection for various purposes is undertaken by several organizations/institutions and individual researchers. The Ministry of Agriculture and its institutions collect mainly local crop varieties and land races. University researchers working on specialized plant groups also collect germplasm, including wild crop relatives. In the country, germplasm is conserved in various ways including protection of habitats in government (national) protected areas, national seed bank (located at Kabanyolo Agricultural Research Institute), gene banks of different crops or plant groups at various research institutes/stations, and botanical or medicinal plant gardens. Herbaria play a complementary role to the collection and conservation of germplasm. This paper discusses the status of germplasm collection and conservation in Uganda.

INTRODUCTION

Uganda is a small country. However, 5 of White's (1983) African biogeographic regions occur in Uganda (the predominantly Lake Victoria mosaic in the south; the Sudanian in the north; the Somali-Turkana in the extreme northeast; the Guinea-Congolian south of L. Albert, and the Afromontane in the mountains). Uganda possesses the highest number of geographic regions on the African continent (Howard, 1991). The country has a diversity of ethnic groups including the Bantu, Nilotic, Nilo-Hamitic, and others (Jameson, 1970). The ethnic groups are further divided into over

20 tribes with different cultures. Utilization of various plant species is to some extent linked to cultural differences. As a result, the distribution of various under-exploited crops and medicinal plants can be associated with spatial settlements of these cultural groups (Male-Kayiwa and Wasswa, 1996).

More than 5000 species of vascular plants occur in Uganda (Stuart et al., 1990; WCMC, 1992). Uganda's forests support about 50% as many species as the richest-known African sites (Howard, 1991). The relatively large forests are protected by the government as forest reserves. Smaller forest remnants, shrubs, and lianas are vulnerable to degradation through agriculture. The main economic activity in Uganda is agriculture, which has resulted in extensive clearing of forests leaving little closed-canopy forest outside government forest-protected areas (Hamilton, 1984).

In Uganda germplasm collection and conservation for various purposes is undertaken by several organizations, institutions, and individual researchers. Those collecting germplasm include the Ministry of Agriculture and its institutions (Kawanda, Namulonge, Kabanyolo, Kalengyere, Ngetta, and Serere—see Figure 1).

These institutions work mainly on commercial crops such as maize, beans, millet, etc. They also collect local crop varieties and land races. Germplasm in Uganda is conserved in various ways (both *in situ* and *ex situ*): protection of habitats in government (national) protected areas, botanical or medicinal plant gardens, the national seed bank, and gene banks of different crops. Herbaria play a complementary role to collection and conservation of germplasm.

CONSERVATION OF GENETIC RESOURCES IN UGANDA

Conservation of Habitats

Conservation of habitats is an important way of conserving genetic resources. The majority of the world's threatened species inhabit the tropical forests. Although these forests cover less than 10% of the earth's surface, they are believed to contain over 50% of the world's species (Wilson, 1985). Conservation of a wide variety of plant species can be justified on the grounds that they are of direct economic importance to humans. Only about 1% of the earth's plants have been thoroughly screened for use (Given, 1994).

Forests, savannas, wetlands, and other natural habitats contain various useful plant resources that are not yet domesticated. These include food and medicinal plants. At least 75,000 plants are edible worldwide yet the main food resources of the world depend on only a few species (Given, 1994). There is potential for many other plants to become food crops, and thousands more species are likely to have desirable characteristics for breeding into existing crop plants (Myers, 1985). Bukenya (1996) listed more than 200 species of non-cultivated edible plants in Uganda, and Kyoshabire (pers. comm.) has listed more than 230 medicinal plants in the area surrounding Bwindi Impenetrable National Park. About 80% of the people in developing countries rely on traditional medicine for primary health care, and 85% of traditional medicine involves the use of plant extracts (Farnsworth, 1988).

Although thousands of plants containing useful chemical substances are known, many are largely unknown outside the regions where they are gathered and used. Species of the tropics and regions with climatic extremes are particularly rich in chemical compounds that protect plants against predation. Only a very small

Figure 1. Agroecological map of Uganda. Numbers next to shaded circles are the following: 1 = Ngetti D.F.I.; 2 = Serere A.R.S.; 3 = Namulonge A.R.S.; 4 = Kabanyolo U.F.; 5 = Kawanda A.R.S.; 6 = Katengyere A.R.I. Agricultural zones: I = high altitude, altitude above 3,000 m, > 1,000 mm rainfall; II = Pastoral dry to semi-arid rangeland zone—*Themeda triandra* grassland, 750–1000 mm rainfall; III = northern and eastern Uganda zone, savanna (short grassland zone), 1000 mm rainfall; IV = southern and western Uganda zone, *Pennisetum purpureum*, 1000–1500 mm rainfall. Map based on World Bank Task Force and Ministry of Agriculture (1987)

percentage of these compounds have been investigated for their direct value to humanity. The list of potentially useful plants requiring investigation is almost endless, especially as we cannot predict what may be of interest in the future (Given, 1994). According to Plotkin (1988), random screening of plant materials for new biodynamic compounds has proved to be very expensive. A more cost-effective method to find new and useful plant compounds is the science of ethnobotany. Ethnobotanical knowledge should also assist in deciding what to collect and conserve. Medicinal plants deserve special attention because of their immense value in averting or treating common illnesses. Their conservation also means retention of the indigenous knowledge

associated with their unique properties and correct application (Damania, 1996). It seems likely that new plant materials of the future would more than pay for the costs of preserving species and developing sustainable harvesting or cultivation (Myers, 1979).

National Parks

Uganda's national parks reflect the extraordinary diversity of the country with a variety of habitats, including lakes, swamps, dense grassland, woodland, rolling plains, forests and mountainous areas. The Uganda National Parks Department was established in 1952. The department manages 10 national parks (Murchison Falls, Queen Elizabeth, Kidepo Valley, Lake Mburo, Rwenzori Mountain, Bwindi Impenetrable, Mgahinga Gorilla, Mt. Elgon, Semuliki, and Kibale—see Figure 2).

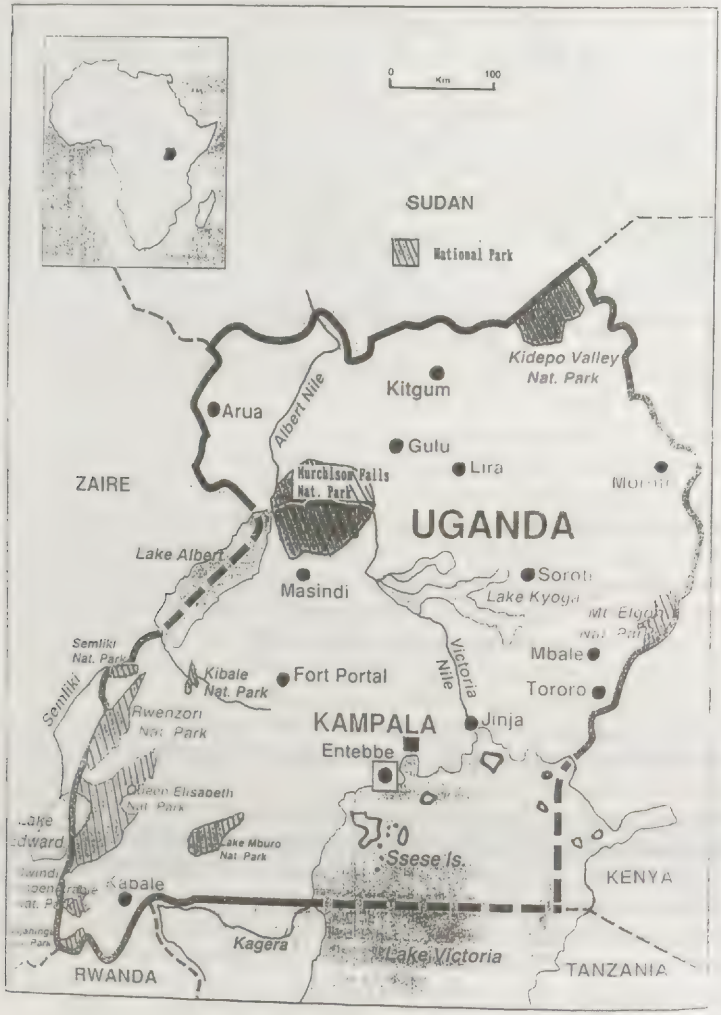


Figure 2. National Parks of Uganda

Each of the parks is to a large extent unique from the others. The parks utilize *in situ* conservation of species. *In situ* methods remain the single most effective means of conserving diversity together with the dynamic environment (Damania, 1996).

The traditional method of species conservation in the parks has been to exclusively allocate the land to flora and fauna to the almost total elimination of human activities. Recently multiple use zones have been set up on a trial basis in a few parks, including Bwindi Impenetrable National Park. These zones are areas adjacent to the park(s). Specific levels of non-timber forest products (medicinal plants and craft materials) are harvested in given amounts by the communities around the parks.

Home Gardens

In home gardens indigenous germplasm in the form of folk varieties or obsolete cultivars, land races, and rare species thrive side by side and are preserved (Damania, 1996). Home gardens provide a considerable amount of species diversity; when a wide range of home gardens in communities are put into consideration, they offer considerable genetic diversity.

The majority of Ugandans live in rural areas and depend mainly on their gardens for subsistence and food security. In the southern part of the country where bananas are a staple food, numerous cultivars of bananas are grown in a single garden. A wide range of vegetables is also included in the diet: *Amaranthus* spp., pumpkin and cocoyam leaves, lima beans, garden eggs, etc. Some of these vegetables (*Solanum anguivi*, *S. nigrum* complex, *Amaranthus* spp., *Gynandropsis gynandra*) are weedy or semi-weedy but preserved by farmers. Medicinal plants are either intentionally grown in the gardens or come up as weeds and are preserved. Even for cash crop production, the peasants mainly grow a mixture of crops: coffee, bananas, sorghum, maize, ground nuts, beans, etc., each of these in a variety of forms/cultivars. As more and more people resort to growing modern crop varieties (with encouragement from agricultural extension workers), fewer local crop varieties are being grown. As a result of education, young people are moving to urban areas. This is changing the culture of the people; they now have a tendency of neglecting the cultivation of local crop varieties.

Other problems connected with conservation of folk varieties, landraces, and rare species are climatic upheavals and poor storage facilities. When there is drought or excessive rains, a lot of crops do not grow to maturity, and germplasm is lost before harvest. When there is low crop yield, most of the harvest is consumed with little or no seed preserved for the next growing season. Few farmers have proper storage facilities for their produce; therefore a lot of germplasm is lost in the post-harvest period. Efforts have been taken by the Ministry of Agriculture (Kawanda Research Station: Post-harvest Section) to develop appropriate technology for handling farmers' crops after harvest (see Figures 3a–3d). There is need for detailed documentation of indigenous agricultural knowledge and the crops grown in home gardens accompanied with collection and preservation of local crop varieties in gene banks.

Botanic Gardens

Botanic gardens provide a mechanism for the introduction and assessment of plants for agriculture, horticulture, forestry, and medicine. They also provide space for multiplication of germplasm, which is used for studies of genetics, variation, and inheritance of characters. The botanic gardens are centers for cultivation of plants from various habitats. With the extensive destruction of habitats (forests, savanna,

Figure 3a. Improved technology for germplasm conservation facilities. Seed drier: Heated from underneath with charcoal or wood. It dries seeds to a low moisture content so that they can be stored for a considerable length of time.

Figure 3b. A granary made of brick, joined using sand and cassava, the latter being a cement substitute. The granary protects food from attack from rodents and other pests.

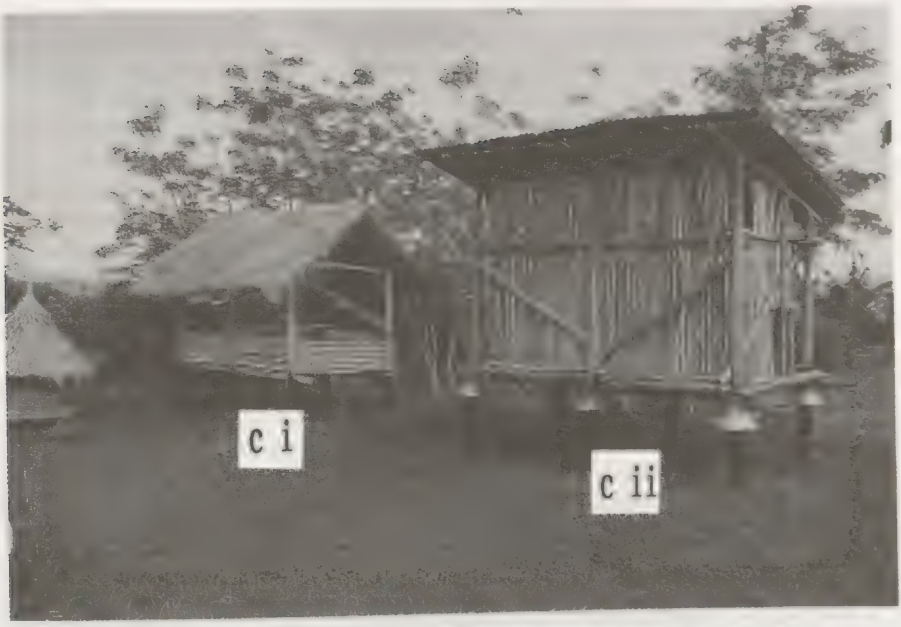


Figure 3c. (i) Crib for storing beans. (ii) Crib for storing maize. Note the rodent protectors on the stands. The stands are also treated with anti-termite chemicals.

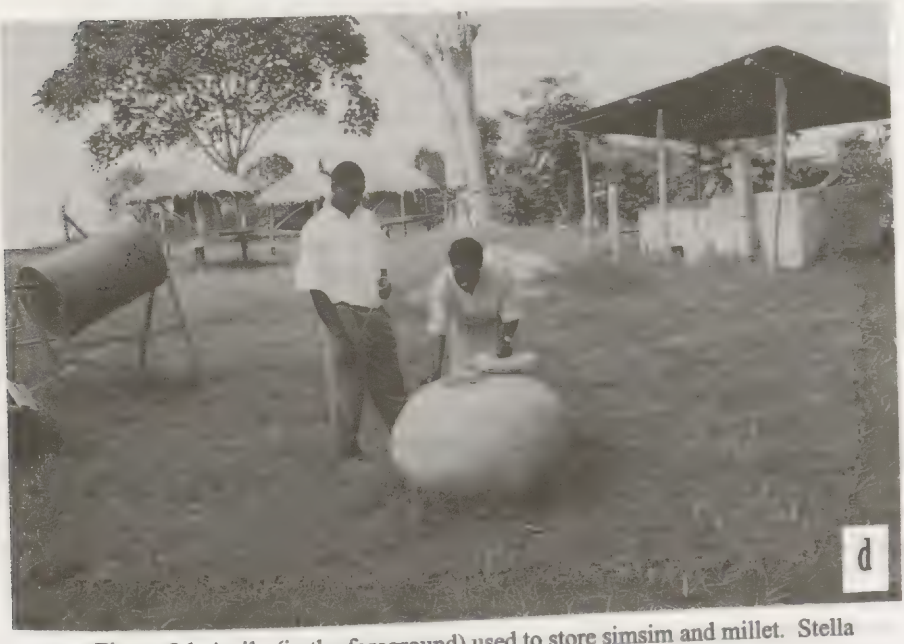


Figure 3d. A silo (in the foreground) used to store simsim and millet. Stella Apio (right) is a post-harvest technician. The technology shown in Figures 3 a–d have been developed at the Kawanda Agricultural Research Institute.

wetlands, etc.), the growth of plants from these habitats is a notable conservation method for the threatened and rare species. Plants are either conserved in cultivation and/or seed form.

Makerere University Botanic Garden is located at Makerere University. It was founded in 1957, and by 1961, the garden was more or less complete. It is approximately two acres in size. It is a collection of indigenous plants and ornamental shrubs representing as much as possible representative genera within families. An attempt was made to collect plants from all parts of the country. The goals of establishing the garden were as follows: gather together a wide range of plant species for teaching botany and related subjects; display plants in an established order in the plots to allow self-instruction; culture and preserve rare and/or endangered species for study and conservation; grow selected aquatic plants some of which are aquatic weeds to increase awareness of their dangers in aquatic ecosystems; propagate selected species for scientific, horticultural, and medicinal purpose; exchange information with outside botanic gardens through seed/literature; provide research facilities in the garden, glasshouse and experimental plots; publish the botanic garden's *Index Seminum*.

By 1970, 20 natural order beds were laid out containing 66 angiosperm families, 257 genera, and 390 species. From the early 1970s, years of turmoil, the Botanic Garden, like other facilities in the country, steadily deteriorated. Deterioration was arrested about 3–4 years ago. The garden requires substantial rehabilitation including re-instating lockable gates, rehabilitation of water ponds, repair of the glasshouse, and the orchid house, reviving the nursery, restocking and re-labeling the plants, repair of store and residential houses, and establishing the post of garden curator to head the garden.

Entebbe Botanic Garden is located on the edge of Lake Victoria, within the township of Entebbe. It was started in 1898 on 70 acres of land, which was natural forest, a small part of which was preserved in its original state. Many specimens of indigenous trees were also left when the land was cleared. The introduction and study of most of the economic crops grown in Uganda today (coffee, cocoa, tea, and rubber) were made through the garden. Experiments on chief economic crops have been taken over by the Agricultural Department Stations, but the garden is still concerned with the introduction and study of ornamental plants and economic plants of potential value. The other function of the garden is to distribute fruit trees and ornamental plants and give technical advice on horticulture and market gardening.

The indigenous trees in the garden include: *Piptadenia africana* (locally known as mpewere in luganda), which produce good quality timber; *Antiaris africana* (locally known as kirundu in luganda), produces barkcloth, beer boats, and timber; *Chlorophora excelsa* (locally known as muvule in luganda), one of the best timber trees in Uganda; *Raphia monbuttorum* (raphia palm), popular for making mats and baskets; *Borassus flabellifer* (borassus palm); *Phoenix reclinata* (locally known as lukindu in luganda); *Podocarpus malinjanus* (locally known as musenene in luganda), a softwood tree; *Ceiba pentandra*; *Euphorbia* spp.; *Lovoa brownii* (locally known as nkoba in luganda); *Ficus* spp.; *Diospyros discolor* (velvet apple); *Musanga cecropioides* (umbrella tree, namaguro in luganda); *Eugenia uniflora*; *Carapa grandiflora* (craftwood tree); *Monodora myristica* (calabash nutmeg, nagamola in luganda), one of Uganda's most handsome indigenous trees; *Cyathea dregei* (tree fern); *Erythrina* spp.; *Markhamia platycalyx* (lusambya in luganda).

Some of the introduced tree species include: *Crescentia cujete* (tree calabash), a native of tropical America; *Ravenala madagascariensis* (traveler's palm), introduced

from Madagascar about 90 years ago; *Annona muricata* (soursop) from the West Indies; *Phytelephas macrocarpa* (ivory nut palm), introduced from South America, its very hard seeds used for making buttons and ornaments; *Eugenia aromatica* (clove tree) from Molucca Islands; *Eugenia jambolana* (jambolam) from Java; *Hura crepitans* (sand-box tree) from South America; *Erythrina cristagalli* from Brazil; *Mangifera indica*, introduced from India; *Couroupita guianensis* (cannon ball tree), native of the West Indies and Guyana; *Roystonea* sp. (royal palm); *Callistemon salignus* and *C. rigidus* (bottle brush tree) from Australia; *Dieffenbachia picta* from the West Indies and *Hylocereus triangularis* (night flowering cactus) from Jamaica.

Medicinal Plant Gardens

Cultivation and conservation of medicinal plants commonly used in Uganda is being done by several people/organizations, including the Rukararwe Rural Development Center in the Bushenyi district in western Uganda. At the Center over 110 medicinal plant species belonging to over 40 plant families are cultivated and conserved for sustainable utilization.

A project at the Natural Chemotherapeutics Laboratory, in Kampala, called Medicinal Plants and Biodiversity Conservation, sponsored by IDRC, started in 1995. It has concentrated on 15 key medicinal plants that were identified during field interviews with the users. These are *Capparis erythrocarpa*, *Carissa edulis*, *Dioscorea praehensilis*, *Dracaena steudneri*, *Erythrina abyssinica*, *Fagara chalybeum*, *Lonchocarpus laxiflorus*, *Mytenus senegalensis*, *Prunus africana*, *Ranvolfia vomitoria*, *Securidaca longepedunculata*, *Spathodea campanulata*, *Steganotaenia araliacea*, *Rhus vulgaris,* and *Warburgia ugandensis*.

Five pilot medicinal plant gardens located in each of the regions of Uganda have been established (Lira in the north, Tororo and Iganga in the east, Kabale in the south-west, and Luwero in central Uganda). Plants are propagated in the gardens by supply of seedlings or cuttings grown by the project coordinator (Mr. Amai). Nurseries where the seeds and cuttings are propagated are also located in all regions of the country. The project works with traditional healers (20 per pilot garden), half of whom are women. The healers are taught and shown methods of propagating and harvesting the required plant materials for medicinal purposes. The aim is to encourage all traditional healers to have medicinal plant gardens so that the plants do not become extinct (Bukenya et al., 1997).

Herbarium

Makerere University Herbarium is known internationally by the code MUH. It is the largest herbarium in the country and was started in 1946. It is housed in the Department of Botany, Makerere University. The original herbarium was approximately 60 square meters accommodating over 50,000 specimens. Entebbe herbarium specimens were incorporated into the herbarium in 1990. The space became too small to accommodate the specimens and activities of the herbarium. With funding from Global Environmental Facility (GEF) ($75,000) and Makerere University ($30,000) a larger herbarium was constructed and opened in 1996. More financial support was obtained from a MacArthur Grant (through the Field Museum of Chicago), DANIDA, and the African Development Bank to outfit the herbarium. The main goals of the herbarium are to direct the collection and preservation of the basic data required for the study, conservation, and management of plant resources and store a

comprehensive reference collection representing the total diversity and distribution of the country's flora. The major problem faced by the herbarium is understaffing. Currently there is one curator, one assistant curator (retired), and two herbarium assistants. The estimated optimum staffing should be 11 people.

COLLECTION AND CONSERVATION OF GERMPLASM BY RESEARCH INSTITUTIONS

Agricultural research is undertaken at Makerere University, Agricultural Research Institutes (Kawanda, Namulonge, Serere and Kalengyere—Figure 1). Many plant species were introduced during the colonial era for possible commercial exploitation. Research stations have their roots in botanical garden type of work, such as plant introduction and evaluation for adaptation (Male-Kayiwa and Wasswa, 1996). Crops were categorized as cash or food crops and priorities set regarding how much research should be conducted. Breeders and pathologists assembled germplasm for evaluation (coffee, bananas, beans, maize, cowpeas, groundnuts, pigeon peas, soybean, finger millet, sorghum, pearl millet, etc). Agronomists evaluated germplasm for forage species.

Research stations were given mandate, over a range of crops, usually those crops grown in the ecological zone where the station is situated (Kawanda mainly for perennials such as coffee and bananas, and Serere for cereals such as sorghum and millet). Stations where germplasm of any crop is kept depends on the crop mandate subdivision. Some duplicates were deposited with genebanks at international research centers (ICRISAT and CIAT). The safeguard of sending duplicates elsewhere has been poorly utilized resulting in loss of genetic stocks either through civil strife or loss of viability through prolonged storage in sub-standard conditions.

For many crops the collection of germplasm in the past was handled by individual breeders. A collective has been developed for sorghum and millet genetic resources activities at Serere (Okello, 1996). In 1976, 1981, 1984, and 1985, missions for sorghum and millets were organized around the country. In 1984 and 1985 the Sorghum and Millets Unit at Serere entered into an agreement with the International Board for Plant Genetic Resources (IBPGR) to collect, conserve, and utilize sorghum and millet germplasm and their wild and weedy relatives to add to the existing world collection. By 1985 materials mainly from India and America contributed 1,002 accessions of sorghum and 101 accessions of finger millet. In 1990, 100 lines of small millets (*Setoria italica*, *Panicum miliare*, *Panicum miliaceum*, *Paspalum scrobiculatum*, and *Echnocloa colosna*) were received from India (Okello, 1996).

Sorghum and millet germplasm at Serere is maintained in the field because cold storage facilities quit functioning about 10 years ago. Cold storage facilities have been restored recently, but there is a scarcity of trained manpower to handle the germplasm. The system of maintaining germplasm is inadequate and leads to losses of genetic resources. The National Sorghum and Millets Improvement Program based at Serere depends on a world collection that exists in the nation. The general objective of this program is to improve yield and quality of the cereals.

Bananas deserve mention because about 75% of the country's farmers grow bananas, and the crop is a staple for 7 million people in Uganda (Karamura et al., 1996). The crop has replaced sweet potatoes and millets in the western and southern regions of Uganda. A banana germplasm collection was established at Kawanda in 1989 (Figure 4).

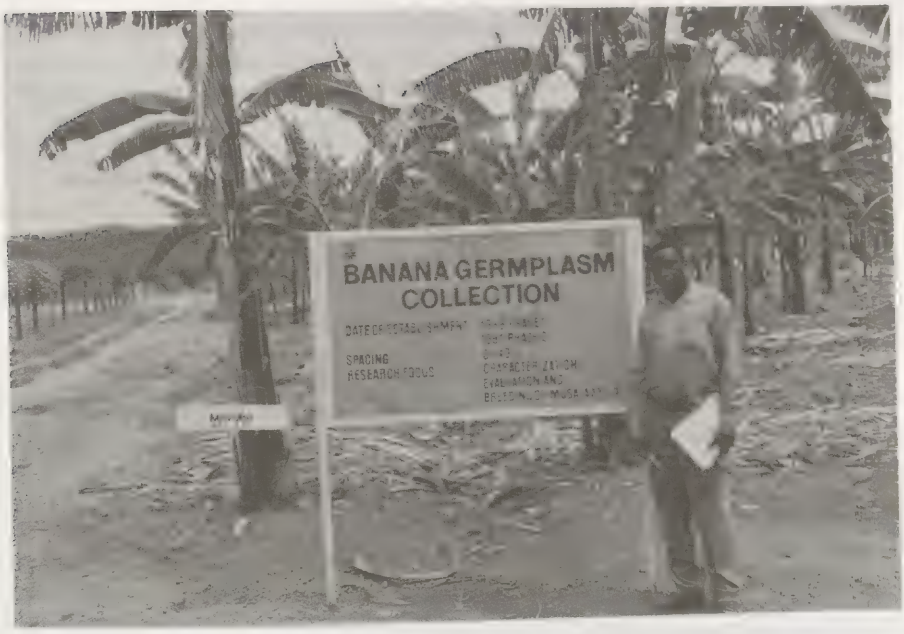


Figure 4. Banana germplasm collection at the Kawanda Agricultural Research Institute. A. W. Okurut (pictured) is the chief technician for the banana germplasm conservation project.

Accessions were obtained from various parts of the country. According to Karamura et al. (1996), the banana germplasm collection consists of approximately 265 cultivars so far identified. This collection includes: highland bananas (AAA) (152 cultivars); beer mutants (AAA) (92 cultivars); dessert bananas (AAA) (7 cultivars; all imported); dessert (Ndizi) and Beer (Kisubi) (AB) (4 cultivars); plantains (AAB) (8 cultivars) and kayinja (for beer) and kivuvu (for beer and roasting) (ABB) (2 cultivars). The above germplasm is maintained in cultivation (Figure 4).

Beans, another very important crop, probably arrived in Uganda in the 18th century (Purseglove, 1969). Serious cultivation of beans in Uganda started in the 1920s, and many introductions were made. By 1960, beans were recognized as a possible remedy for protein malnutrition, which was widespread within areas where bananas-plantains were the predominant staple (Male-Kayiwa et al., 1996). Bean research has mainly been directed toward identifying disease-resistant and high-yielding genotypes. The National Bean Program at Namulonge over the years has utilized *Phaseolus* genetic resources from land races and introductions from abroad. Vigorous collections of land races by bean breeders were undertaken, and accessions were obtained from individual farmers, open markets, and shops throughout the country. By 1984, a total of 204 land races were collected, mainly of *Phaseolus vulgaris* and a few samples of *P. lunatus*, *P. acutifolius,* and *Vigna mungo*. The collection also included 130 breeding lines (K-series) developed from the hybridization program and 445 introductions from abroad. Most of this material was lost in the 1982–85 period of civil strife (Male-Kayiwa et al., 1996). Collection resumed in 1986. Land races are acquired from individual farmers,

markets, and agricultural extension staff. By 1992, 140 landraces were held in collection at Kawanda. Breeding lines are continuously received from CIAT.

Lack of proper storage facilities is a major problem for conservation of bean germplasm. Seed viability needs to be maintained for continued availability of the sample. Due to lack of storage facilities, samples have been lost through bruchid attack or loss of viability. Samples are frequently regenerated (every two seasons) as a solution but this exposes the germplasm to loss through natural hazards, contamination, and, in some cases, genetic drift (Male-Kayiwa et al., 1996). Currently techniques like using of silica gel to dry small seed samples to low moisture content and keeping samples in tightly closed plastic bottles are being tried.

Cowpeas (*Vigna anguiculata*) and pigeonpeas (*Cajanus cajan*) are two of the major grain legumes in Uganda. They are mainly grown in the drier parts of the northern and eastern regions of the country. In 1987, the Makerere Grain Legume Improvement Program began to assemble germplasm of these crops from various national and international centers. Genetic materials were introduced from Kenya, IITA in Nigeria, and ICRISAT in India to add to the local collection. By 1991, 843 accessions of cowpeas and 356 accessions of pigeonpeas were assembled (Rusoke and Rubaihayo, 1996).

A research program on tomatoes started at Makerere University Agricultural Research Institute at Kabanyolo in 1987. By 1992 over 150 accessions were collected mainly from outside the country (America, India, and Europe). About six accessions were obtained locally (Rubaihayo and Rusoke, 1996).

Cassava (*Manihot esculenta*) and sweet potatoes (*Ipomoea batatas*) rank second and third to bananas as staple foods of the country. In 1986 germplasm collections of these crops supported by IBPGR was carried out in 11 districts located in the eastern, central, and western parts of the country. A total of 286 cassava accessions, 433 sweet potato accessions, and 2 yam samples were collected and assembled at Serere Research Station and duplicated at Namulonge Research Station. They are maintained in a field genebank active collection and are cultivated every year from clones. This type of maintenance requires a large amount of field space, is labor intensive, and exposes the materials to disease infection. There is no protection against grazing animals, pests, drought, hailstorms and pathogens. However, plans are under way to transfer collections to *in vitro* culture after installation of the tissue culture laboratory at Namulonge (Mwanga and Otim-Nape, 1996).

Potato (*Solanum tuberosum*) research is carried out at particular stations, Kalengyere Highland Crop Research Station being a major one. As a safety precaution tuber samples of each accession are stored in cold storage until a new harvest is obtained. The stores are constructed from locally available low-cost materials (Mwanga and Otim-Nape, 1996).

Efforts were taken in the early 1960s to collect and conserve forage germplasm (mainly grasses) at Namulonge, Makerere University Farm, Kabanyolo, and at Serere. In 1972 there were 147 grass accessions at Namulonge. Of these, 111 came from Uganda, 19 from Kenya, 7 from Tanzania, 1 from Malawi, 2 from Ethiopia, 3 from Zambia, and 4 from Zimbabwe. These accessions belonged to nine grass genera: *Panicum*, *Brachiaria*, *Hyperrhenia*, *Cymbopogon*, *Setaria*, *Paspalum*, *Pennisetum*, *Cenchrus*, and *Cynodon*. A forage germplasm at Kabanyolo includes some 36 genera of legumes and 9 genera of grasses. These came from ILCA, Florida (United States), Kitale (Kenya), Kenya Seed Co., Tengeru, Arusha (Tanzania), and within Uganda.

Exotic accessions of grasses and legumes have also been collected to increase the genetic base. These materials have either been conserved in field germplasm or genebanks. The country lacks a proper genebank, although there are plans to establish one with assistance from IBPGR and USAID (Sabiiti and Mugerwa, 1996).

Individual researchers at research institutions collect and conserve germplasm of particular plant groups. Table 1 is an example. Figure 5 shows how such germplasm is conserved in desiccators.

Table 1. Accessions of Solanaceae collected and conserved by R. Bukenya-Ziraba, Department of Botany, Makerere University.

Species	No. of accessions	Locations and dates of collections
Solanum aculeastrum	10	Iganga, Kabarole, Kabale, Bushenyi, Masaka, Mityana, Mbarara, 1989, 1990, 1991, 1996
S. aculeatissimum	4	Bundibugyo, Kabale, 1991, 1995, 1996
S. aethiopicum	21	Kampala, Mbale, Masindi, Hoima, Bushenyi, Mukono, Jinja, 1982, 1990, 1992
S. anguivi	23	Rukungiri, Kabale, Kabarole, Masindi, Bushenyi, Jinja, Kampala, Masaka, Mpigi, Mbarara, Mityana 1982, 1990, 1991, 1992
S. gilo	26	Kampala, Mityana, Mpigi, Mukono, Bushenyi, Kabarole, Jinja, Tororo, Mbale, Luwero, 1982, 1990, 1991
S. incanum	6	Kampala, Kabarole, Bundibugyo, Tororo, Masindi 1990, 1991, 1992
S. linnaeanum	3	(seed from Birmingham, UK), cultivated in the experimental garden, 1986
S. macrocarpon (wild)	20	Kampala, Mityana, Kabale, Mbarara, Bushenyi, Bundibugyo, 1986, 1990, 1991, 1995
(semi-wild)	5	Mityama, Masaka, Jinja, Mubende, 1990, 1991
(cultivated)	18	Kampala, Mpigi, Masindi, Mukono, Mbale 1990, 1991, 1992
*S. mammosum**	2	Kampala, 1991
S. melongena	4	Mityana, Mukono, Jinja, Kampala, Kabarole 1990, 1991
S. nigrum complex (8 spp.)	37	Kabale, Rukungiri, Masindi, Hoima, Bundibugyo, Kampala, Kabarole, Mbale, Kisoro (Australia and Europe) 1990, 1991, 1992, 1994, 1995, 1996
*S. seaforthianum**	2	Kampala, 1990
*S. wrightii**	3	Mityana, Kabarole, Jinja, 1990
Discopodium penninervium	1	Kisoro, 1995
Physalis peruviana	2	Kabale, Bundibugyo, 1990, 1994
Nicotiana tabacum	1	Bundibugyo, 1995

*Ornamental

Figure 5. Germplasm conservation (in desiccators) in the laboratory of the author (April 1997).

CONCLUSIONS

About 20–30 years ago, different regions in Uganda had different food and staple crops. Today the country is experiencing food shortages because diversity in feeding habits and crops has been lost, putting pressure on a few food crops, such as bananas, maize, rice, potatoes, and cassava and leaving many others to become extinct. Genetic diversity present in cultivated, wild, and weedy forms needs to be conserved before these forms are lost forever. It is essential to embark on timely collection missions in collaboration with national scientists at appropriate times. The various methods of germplasm conservation should compliment one another. *In situ* conservation facilitates continuous evolution in response to the natural selection pressure while *ex situ* conservation in well-maintained genebanks ensures future supply of this irreplaceable natural resource.

ACKNOWLEDGMENTS

Thanks to the staff at Kawanda Agricultural Research Station especially, A. W. Okurut (Banana Project), S. Apio (post-harvest section) and Mr. Yiga (database section) for discussions and provision of the relevant information. Thanks to Mr. J. Wasswa for providing information on germplasm issues. I am grateful to L. Guarino (IPGRI-Nairobi) for advice and assistance in processing slides and photographs.

REFERENCES

Bukenya, Z. R. 1996. The Non-cultivated Edible Plants of Uganda. NAPRECA Monograph Series No. 9, NAPRECA, Addis Ababa University.

Bukenya, Z. R., Doenges, P., Duez, P., Lejoly, J. and Ogwal-Okeng, J. 1997. Medicinal Plants Sub-sector Review, Pharmacopoeia Promoting Programme, Preparatory Study, Final Report.

Damania, A. B. 1996. Biodiversity conservation: a review of options complementary to standard ex-situ methods, Plant Genetic Resources Newsletter, 107: 1–18. IPGRI/FAO.

Farnsworth, N. R. 1988. Screening plants for new medicines. *In*: Biodiversity. E. O. Wilson, ed. National Academy of Sciences, Washington, D. C.

Given, D. R. 1994. Principles and Practice of Plant Conservation. Timber Press, Portland, Oregon.

Hamilton, A. C. 1984. Deforestation in Uganda. Oxford Univ. Press, Nairobi.

Howard, P. C. 1991. Nature Conservation in Uganda's Tropical Forest Reserves. IUCN, Gland, Switzerland and Cambridge, UK.

Jameson, J. D. 1970. Agriculture in Uganda. 2nd Ed., Oxford Univ. Press, Nairobi.

Karamura, D. A., Karamura, F. B. and Rubaihayo, P. 1996. Variation in highland bananas of Uganda, and prospects for improvement. *In*: Proceedings of the 1st National Plant Genetic Resources Workshop: Conservation and Utilization. Kampala, Uganda.

Male-Kayiwa, B. S. and Wasswa, J. M. 1996. Introduction to plant genetic resources activities in Uganda. *In*: Proceedings of the 1st National Plant Genetic Resources Workshop: Conservation and Utilization. Kampala, Uganda.

Male-Kayiwa, B. S., Musaana, S. M., Opio, A. F. and Sengooba, T. 1996. Bean germplasm collection, evaluation and utilization in Uganda. *In*: Proceedings of the 1st National Plant Genetic Resources Workshop: Conservation and Utilization. Kampala, Uganda.

Mwanga, R. O. M. and Otim-Nape, W. 1996. Collection, conservation and utilization of root and tuber crops. *In*: Proceedings of the 1st National Plant Genetic Resources Workshop: Conservation and Utilization. Kampala, Uganda.

Myers, N. 1979. The Sinking Ark. Pergamon Press, Oxford.

Myers, N. 1985. The Gaia Atlas of Planet Management. Pan Press, London.

Okello, J. R. 1996. Collection, conservation and utilization of sorghum and millet germplasm. *In*: Proceedings of the 1st National Plant Genetic Resources Workshop: Conservation and Utilization. Kampala, Uganda.

Plotkin, M. J. 1988. Traditional knowledge of medicinal plants: The search for new jungle medicines. *In*: The Conservation of Medicinal Plants. O. Akerele, V. Heywood, and H. Synge, eds., Proceedings of an International Consultation, 21–27, March, 1988, Cambridge Univ. Press, Chiang Mai, Thailand.

Purseglove, J. W. 1969. Tropical Crops: Dicotyledons. Longman Group Ltd., London.

Rubaihayo, P. R. and Rusoke, G. D. 1996. Performance of local and exotic germplasm of tomatoes (*Lycoperscon esculentum*) in Uganda. *In*: Proceedings of the 1st National Plant Genetic Resources Workshop: Conservation and Utilization. Kampala, Uganda.

Rusoke, D. G. and Rubaihayo, P. R. 1996. Evaluation of introduced cowpea (*Vigna unguiculata*) and pigeon peas (*Cajanus cajan*) varieties in Uganda. *In*: Proceedings of the 1st National Plant Genetic Resources Workshop: Conservation and Utilization. Kampala, Uganda.

Sabiiti, E. N. and Mugerwa, J. S. 1996. Forage genetic resources in Uganda. *In*: Proceedings of the 1st National Plant Genetic Resources Workshop: Conservation and Utilization. Kampala, Uganda.

Stuart, S. N., Adams, R. J. and Jenkins, M. D. 1990. Biodiversity in Sub-Saharan Africa and its islands, Conservation Management and Sustainable Use. IUCN, Gland, Switzerland.

White, F. 1983. The Vegetation of Africa. UNESCO, Paris.

Wilson, E. O. 1985. The biological diversity crisis. Bioscience 55(11): 700–706.

World Conservation Monitoring Centre. 1992. Global Biodiversity: Status of the Earth's Living Resources. Chapman and Hall, London.

ACRONYMS

CIAT = Central International de Agricultural Tropical
IBPGR = International Board of Plant Genetic Resources
ICRISAT = International Crops Research Institute for the Semi-Arid Tropics
IITA = International Institute for Tropical Agriculture
ILCA = International Livestock Center for Africa

THE STATUS OF PLANT GERMPLASM CONSERVATION IN CAMEROON

Peter A. F. Foncho
Bioresources Developments and Conservation Program-Cameroon
B.P. 2626
Mesa, Yaounde, Cameroon

SUMMARY

Endowed with a great diversity of climates and ecological riches, varying lateritic soils and topography, Cameroon is well-placed to sustain an enormous spectrum of biodiversity. The scope and content of this paper discusses the prevailing situation of plant germplasm conservation in Cameroon within the context of its varied agro-climatic zones, existing forest potentials, ongoing forest conservation programs/projects, and major governmental and non-governmental organizations operating in the domain of plant conservation environmental protection and natural resources management.

The paper concludes with an appraisal of the current programs and approaches to forest conservation and proposed strategies to inculcate into the national mindset the concept and practice of plant germplasm and natural resources conservation and management.

INTRODUCTION

With an area of 474,000 km^2, Cameroon extends between latitudes 2° and 13° North for 1300 km (Figure 1). The country has a great diversity of climates and ecological zones, ranging from humid tropics near the coast where annual rainfall is among the heaviest in the world to the sahelian zone, which has a 9- to 10-month dry season. The regular succession of climate zones from south to north is broken by intervening mountains, and plateaus, which affect both rainfall and temperature. As shown in Figure 2, four main types of climatic zones can be distinguished in Cameroon:

- Humid tropics (Zone I)—very heavy rainfall and a short dry season. Rainfall in this zone can attain up to 5000 mm with 250 rainy days per year.
- Sub-humid tropics (Zone II)—rainfall in this area, which includes the forest zone of the south and the southern areas of the central savanna area of Cameroon, is between 200 mm and 1500 mm per year.
- Sudanese zone (Zone III)—two seasons: rainy and dry, of equal length. Although rainfall may attain 1600 mm per year, evapotranspiration rates are higher than in the tropical sub-humid zone located to the south. The mean maximum temperature varies between 26° and 28° C and the minimum between 16° and 18° C This is considered to be a very healthy climate zone.
- Sahelian zone (Zone IV)—a short rainy season and a long dry season. Total rainfall is less than 100 mm distributed over a three-month period. Temperatures may reach 30°C, and evapotranspiration rates are very high.

POPULATION AND ENVIRONMENT

Approximately 65% of Cameroon's population of 11.5 million inhabitants (1990) live in rural areas, and about 70% of the active labor force in the country is

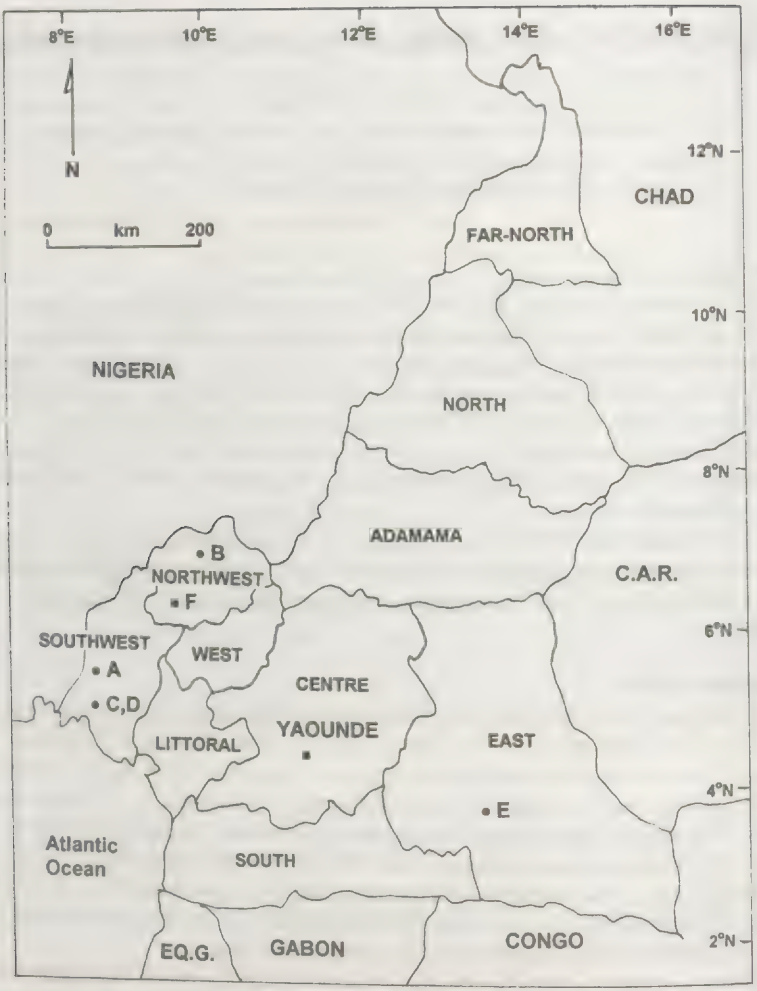


Figure 1. Cameroon's 10 administrative provinces (regions) and some major forest conservation projects. A = Korup Forest, B = Kilum-Ijum Mountain Forest, C, D = Limbe Botanical Garden and Buea Mountain, E = South Eastern Forest, F = Bafut-Ngemba Community Forest.

engaged in agro-pastoral activities. Population in the rural sector is very unevenly distributed with the most densely population areas being the fertile volcanic highlands of the west and northwest. Specialization of the activities of Cameroon's rural sector population is mainly determined by considerations such as climate, soils, and topography, which are also used to determine density.

Rapid population growth (3% annually), coupled with the poor management of the environment and climatic hazards, have exposed Cameroon's natural resources, especially plant germplasm, to rather rapid degradation.

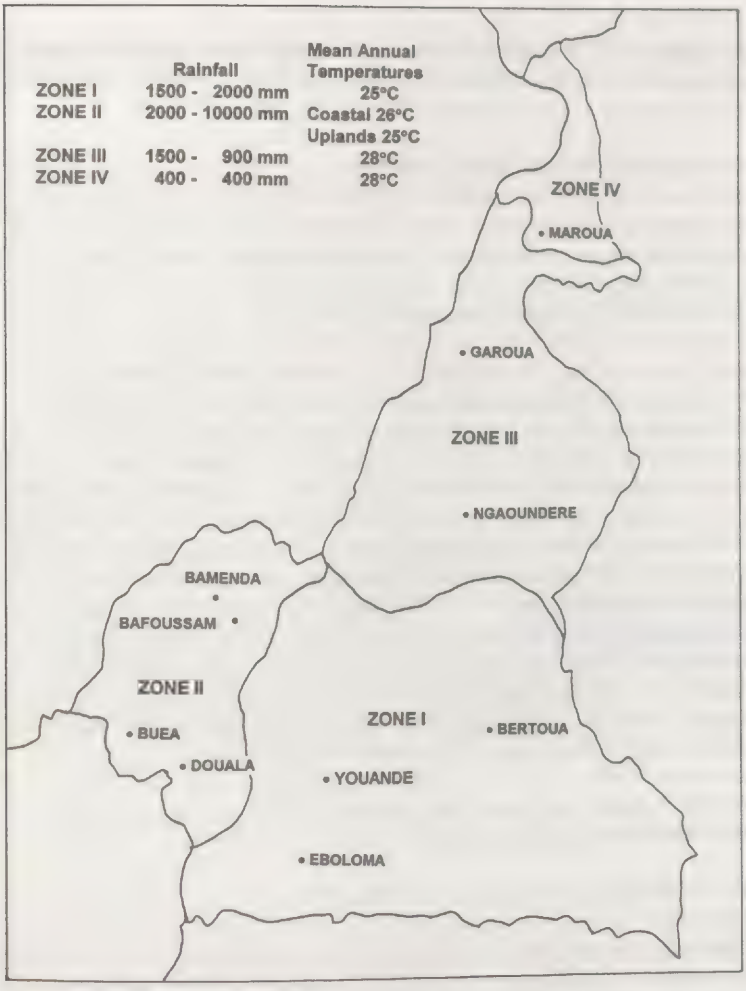


Figure 2. Cameroon's climatic zones and their respective temperature and rainfall.

In spite of the overall low population density and a low level of industrialization, each of the above ecological zones has its own specific environmental and plant conservation problems.

- Sahelian north—affected by soil erosion and desertification mainly caused by climatic hazards. Overgrazing also contributes to the intensification of these phenomena. Other causes include the farming practices (slash and burn practice), the collection of fuel wood, and frequent bush fires.
- Sudanese zone (the highlands of the west)—population growth has led to a gradual overexploitation of the mountain forest, and vegetation cover, thus leading to soil erosion.

• Southern and coastal regions (humid and sub-humid zones)—slash and burn practices, coupled with indiscriminate exploitation of the forest, have contributed immensely to the degradation of the environment, including the flora.

THE STATUS OF CAMEROON'S FOREST

Cameroon stands as a frontier of forest destruction. To the north and west lie countries ravaged by deforestation. To the south and east lies the Congo basin, a vast area of virgin rain forest, while Nigeria, the western neighbor, has lost over 90% of tropical moist forest. The Democratic Republic of Congo (formerly Zaire) contains about one million km^2 of large undisturbed tropical forest.

Cameroon has 207,165 km^2 of closed forest and 47,212 km^2 of savannah forest. This places Cameroon second to Congo-Kinshasa in biodiversity potential in all Africa. National legislation in Cameroon aims to place 20% of the forest under protection status. However, only 8% has been mapped as "Reserves," and of this, at least 10% is being encroached upon illegally. Of the 17.5 million ha of closed forest in Cameroon, harvesting covers an area of 7.2 million ha (less than 50% of the remaining forest). Rampant deforestation and forest degradation have resulted in loss of biodiversity, soil erosion, habitat fragmentation, and desertification. Between the pressures of loggers and farmers, tropical forest in Cameroon is rapidly disappearing; in the last ten years, the total area of closed forest has been reduced by about one million hectares.

Consequently, the Cameroon government, through its Ministry of Environment and Forest, and in collaboration with other non-governmental organizations (both national and international), notably WWF International, have jointly set out five objectives and strategies: development of a national program of conservation and sustainable development; assistance to bilateral and multi-lateral agencies and PVOs in the development of environmentally appropriate projects; development of national environmental education program; development of a land-use plan, and advice to government on environmental issues.

CONSERVATION PROGRAMS AND PROJECTS

Korup Project

An increasing number of projects in Cameroon demonstrate how tropical forest areas can be conserved and sustainably managed (Figure 2). The best-known of these is the Korup Project, based in the Indian Division of the southwest province. The Korup Project is one of the largest integrated conservation and development projects in Cameroon, covering an area of 4,500 km^2. The aim of the project is to combine conservation and management of a strictly protected national park, with rural development in a surrounding "support zone." Overall, the scheme is envisaged to show how a forest can pay for its own protection and conservation, bringing about a significant improvement for the local people.

The Korup Project area includes three forest reserves: Nta-Ali, Rumpi Hills, and Ejagam, as well as park buffer zones for agriculture, watershed protection, and hunting. The unique primary rain forest of Korup has a large number of species. It contains more than 400 varieties of trees, shelters 25% of all the monkey species in Africa, and has over 325 birds species and over 174 reptile species. It is also very old. During times of past climate adversity and forest retreat, Korup remained cloaked in tropical forest.

Within this glacial refugium, evolution has continued for thousands of years. An immense reservoir of biological resources has survived almost completely untouched by man.

Protection and management of the national park have been integrated into the local economy. Thus, park development has been aligned with environmental education, scientific research, tourism development, rural development, sustainable natural resources utilization and use of non-timber products, as well as preservation of facilities in response to the basic needs of the people of the park area. A remarkable achievement of the Korup Project is the discovery of the liana, *Ancistrocladus korupensis* (*Ancistrocladaceae*) as being active against the human HIV *in vitro*.

Kilum-Ijim Mountain Forest Project

The Kilum or Oku mountain is the second-highest peak in west Africa (about 3011 m) after Mount Fako-Cameroon. The Oku montane forest, which constitutes the last significant remnants of an endangered ecosystem worthy of biodiversity consideration, has significant and immense biological and geomorphological features such as:

- rich in alpine bamboo and unique in flora and fauna assemblages, resembling only those of the East African mountain forests. A report of medicinal and potent plants of the montane forest zone has been developed from the ethnobotany studies of the Kilum Mountain Project. The report identifies 161 plant species of 70 different families by scientific and local names, habitat, habit, distribution in habitat, and medical use:
- constituting a huge resource reservoir for fuel wood, building and carving material, medicinal plants and herbs, honey, and bush meat;
- acts as a powerful watershed for such big rivers as Katsina Ala (flowing into Nigeria), the Noun, and the Menchum;
- acts as a sponge during the rainy season, absorbing water and then releasing it during the dry season, thus serving as a global climatic regulator, and attracting researchers and tourists;
- helps in soil conservation.

As a result of excessive forest clearance, reckless and destructive farming practices, uncontrolled grazing, hunting, and bushfires, the Kilum-Ijim Mountain Conservation Project was launched about 8 years ago with the unique goal that "the representative areas of Cameroon montane forest covering 20,000 ha are conserved in the long term." Within this broad objective lies the target of the project, which is to ensure that the biodiversity extent and ecological processes of the Kilum-Ijim forests are maintained and the forests sustainably and rationally exploited by the local community. It is assumed that sustainable limits to forest-use can be identified and that these will be acceptable to the local people since they cannot survive without utilizing the forests. There is the need for a management system in which the user-communities play a central role. This approach is expected to offer the best prospect for long-term conservation.

The Kilum-Ijim Mountain conservation project envisages that at least five community forests will be in operation by the year 2000. These user groups will be working actively to conserve the forest and its biodiversity from extinction. Furthermore, by raising awareness about the intrinsic value of the forest, the project

expects to promote initiatives that will improve the economic and financial value of the forest. Besides institutional strengthening, sustainable livelihood and monitoring are the key elements in the project's strategy.

The strategy is, indeed, working. On the Kilum side of the mountain, the entire forest boundary has been agreed upon, marked, surveyed, and mapped since 1993, with the active collaboration of local traditional chiefs and community leaders. On the Ijim side, agreement on the boundaries or limits has been reached with more than 85% of the communities.

It is generally agreed with the communities that no farming will be carried out within the agreed limits or boundaries of the forest. Any intrusion detected is handled by the traditional chiefs and the administrative authorities, and sometimes with the help of the project.

In spite of the successes scored, the project is still facing some problems:

- some members of the community contravene the farming ban by applying pressure through various channels to be given access to farmland inside the boundary;
- uncontrolled grazing by large herds of goats causes serious damage to understory vegetation and to tree regeneration;
- one of the most serious problems being faced by the authorities of the project is the non-cooperation of "grazer elites" residing out of the locality. These elites use their privileged position in government or their financial power to bully the local authorities into submission, thereby frustrating community forest initiatives;
- another serious problem is what is generally referred to in the area as "Plantecam Mafia," which sponsors the wanton exploitation of the *Prunus africanum*. These illegal exploiters are protected by some unscrupulous well-placed people. About 80% of the *Prunus africanum* has already been exploited.

Southeast Forest Project

This project comprises the forest reserves of Boumba-bek, Nki, and Lobeke. It involves the protection of 8040 km^2 of biologically important, moist evergreen and semi-deciduous closed forest. Basically, this is a conservation and integrated development project that is envisaged to rise to an eco-tourism program capable of creating employment opportunities, increasing incomes of forest-edge populations, and cutting down on poaching and other illegal hunting practices.

Marine and Coastal Ecosystems Program

This program is still at the conception and formulation stage. Information already collected from marine and coastal ecosystems surveys has been compiled into a database by the WWF-Cameroon Program Office. This information is being analyzed with the aim of drawing up an integrated conservation and development program.

Northern Cameroon Montane Forest Survey

Through the WWF-Cameroon Program Office, a draft report has been drawn up on the Montane Forest Survey of Tcabal Mbabo in northern Cameroon. The survey provides a description of vegetation types and accounts of flora, current vegetation management, and the use of plants. Alongside this survey is Waza-Logone Project,

which was initiated by the World Conservation Union and aimed at rehabilitating the floodplains of the Waza-Logone region of the far north province of Cameroon.

Education Program

In 1992, the Cameroon National Environmental Education Program (CNEEP) was launched with the mission to create a broad-based environmental education program and supervise its implementation in Cameroon. This objective was expected to be achieved by raising public awareness through media actions, promoting environmental education in its formal system, and enhancing the capabilities of communities to use natural resources wisely.

In pursuance of the CNEEP, a new environmental education initiative jointly introduced and supported by the European Union (through the STABEX Program), and the Living Earth Foundation, was created in mid-1997. The initiative known as the Cameroon Environmental Education Support Project (SEESP) has as its goal the development and promotion of environmental education in schools and the local commentates through the empowerment of various stakeholders—teachers, women, youth, community leaders, and the general public, in the sustainable use of natural resources. Beginning in September 1997, environmental education will become part of the national curriculum in all primary schools in Cameroon.

The Bafut-Ngemba Forest Reserve

The concept and practice of community-based forest conservation is rare in Cameroon. However, the isolated case of the Bafut-Ngemba local council reserve in Mezam Division, Northwest Province, is worthy of mention. The Bafut-Ngemba Forest Reserve, created in the early 1940s, covers a land area of about 3000 ha and occupies parts of Akum, Bamendakwe, Awing, and Santa villages. The purpose of its creation has been to protect the community's natural resources in the interest of the local population. Customary rights in the forest, such as tree harvesting for domestic use, the search for wild fruits and plants of medicinal value, were retained. The natural vegetation of the reserve over the years has been supplemented with a plantation forest of exotic eucalyptus trees.

Security measures that were initially in place in the form of forest guards had long been scrapped exposing the reserve to uncontrolled wood-harvesting for commercial purposes and encroachment by crop and livestock farmers. The reckless exploitation of the reserve, apparently due to lack of an operational management plan, has resulted in the loss of watershed properties, loss of grazing potential of the area, scarcity of wood products, and loss of flora and fauna.

***In vitro* Plant Germplasm Conservation**

The concept of *in vitro* plant germplasm conservation in Cameroon is quite new and rare. The only case worthy of mention is that of the Rootrep Project of the Institute of Agricultural Research for Development (IRAD) in Ekona. The Rootrep Project has been making attempts to conserve food crop germplasm, especially yam accessions (*Dioscorea* spp.).

Limbe Botanical Garden and Buea Mountain Project

These two projects are based in the Fako Division of the Southwest Province. Their raison d'être is also to conserve the phytogenetic material that may be eco-specific of this area around the Cameroon mountain ecosystem.

PRINCIPAL ORGANIZATIONS INVOLVED IN GERMPLASM CONSERVATION IN CAMEROON

Ministry of Environment and Forest

In a bid to demonstrate its concern and commitment to struggle for environmental protection, sustainable rural development, and biodiversity conservation, 10 years ago the Cameroon government created the Ministry of Environment and Forest (MINEF). The first task of the MINEF was the drawing up of Cameroon's Tropical Forestry Action Plan (TFAP), followed later by the National Environment Management Plan. In April 1989, international financiers and development organizations attended a conference in Yaounde to discuss the Cameroon TFAP's 64 proposed projects at a total cost of C.F.A. 45.3 billion. The program, envisaged to be implemented over a period of ten years, aimed to develop the forest by mobilizing the entire resources of the forestry sector. Under Cameroon's TFAP, biodiversity remains intact in reserve areas for future research and development.

The National Environment Management Plan (NEMP) was elaborated through national and regional consultation meetings and seminars in 1993–94. The NEMP formulated strategies and specific actions to enhance the protection of the environment and the rational management of Cameroon's natural resources. Overall, the Cameroon MINEF provides the pivot for the environmental forestry and biodiversity programs/projects of most national and international NGOs and organizations.

The World Wildlife Fund-Cameroon Program Office (WWFCPO)

Although not yet a full member of World Wildlife Fund International (WWFI), the WWF-CPO was constituted in 1990. As the rich biodiversity of Cameroon's forests continues to attract national and international attention, WWF seems to have been one of the first international partners to have intervened to rescue the country's flora and fauna.

Specific project achievements of the WWF-CPO include the establishment and management of the Korup National Park in the Southwest Province. It is one of WWF's largest integrated conservation and development projects in Cameroon. Collaboration with the government is very satisfactory, and the inter-ministerial coordination committee for Korup is now fully functional. Other projects and activities of the WWF-CPO include:

- a draft report already drawn up on the Montane Forest Survey of Tcabal Mbabo in northern Cameroon;
- the conception and execution of the southeast forest projects;
- a completed report of medicinal and potent plants of the montane forest zone developed from the WWF-CPO ethnobotany of Mount Kilum-Ijum project in the Northwest province;
- the WWF contributed to the drawing up of the GEF/biodiversity program for Cameroon and lobbied through the World Bank for good forestry laws in Cameroon.

More is expected to be done following the bilateral agreement signed by WWF-CPO and WWF Netherlands.

Living Earth Foundation

Living Earth (LE) began work in Cameroon in 1989 in partnership with the Ministry of Education with the introduction of environmental education in schools and the raising of public environmental awareness. Living Earth had *inter alia* provided in-service training on environmental education practices focusing on content, methodology, and teaching aids, as well as set up grassroot networking groups for Living Earth and conservation initiatives known as Living Earth Groups. This approach is hinged on the consideration that education and conservation are inseparable. The initial achievements of Living Earth served as a springboard for the new initiative—Cameroon Environmental Education Support Project (CEESP), which seeks to provide information and environmental education resources for individuals and local initiatives involved in promotion of sustainable use of natural resources.

Some environmentalists and conservationists have identified ignorance and poverty as some of the cardinal causes of the loss of phytogenetic resources and environmental degradation, and perceived environmental education as raising public environmental awareness as an integral part of the solution. Education's role, therefore, is to empower and inform so that everyone can have a positive role in improving and sustaining the environment with its natural resources. This may explain why Living Earth, with its global mission, seeks to use education to bring about a new generation of consumers, producers, and decision-makers who understand the central importance of environmental protection in development and take part in conservation action.

In order to assist the government of Cameroon and NGOs (both national and international) in this campaign, media coverage of environmental and conservation issues are envisaged to be stepped up by LE so as to boost information dissemination on sustainable resource management given the agenda-setting role of media in shaping public opinion on issues of common concern.

BDCPC-Bioresources Development and Conservation Program-Cameroon

The BDCP-Cameroon, established in 1991, is a non-governmental and non-profit national organization that operates within an international networking structure, the BDCO-International. It is a platform for a collaboration of natural products scientists, environmentalists, and industrialists, aimed at the development of biodiversity needs of people living in the tropical countries with environmental management.

BDCP-Cameroon's major activities center, *inter alia*, around the following themes:

- collection and collating of available information on the uses of African plants with special reference to indigenous food crops, medicinal and aromatic plants, and industrial crops;
- monitoring of selected ecologically sensitive zones for biodiversity loss;
- conservation of tropical African forests by encouraging basic research on various land-use options and on the sustainable utilization for tropical forest plants;

• initiation and encouragement of efforts by local communities for conservation of biodiversity as a feasible tool and exploitable resource for sustainable economic development.

The BDCPC mission program areas, approach, and activities have necessitated the formation of five working groups whose duties are to define, orient, and monitor activities. These groups include: biodiversity conservation and monitoring; natural resources developments; horticulture; policy and social issues; and biodiversity prospecting.

In order to realize its goals, some pilot projects have been initiated in the following areas:

• information management—the establishment of an off-line database to record information on the economic botany of African plants, including their botanical identification, medicinal uses, local names, chemical constituents, potential industrial application, and reported pharmacological activities and toxicity profile;

• social forestry projects—assisting rural commentates in cultivating selected tree crops for food, fuel, wood, and as barriers to check erosion in farms;

• biodiversity monitoring—conducting an inventory of flora and fauna in the forest of the various regions of the country. The project is envisaged to provide basic data that will help in the development of better forest management strategies.

The program also plans to assist communities in the development of parks, nature reserves, and biological gardens in the locations close to protected areas to serve as buffer zones and extractive reserves.

CONCLUSIONS

In a natural resource-based economy like that of Cameroon, where poverty seems to be inextricably linked to environment in varied and diverse ways, about two-thirds of the population that lives in the rural areas derive their main income from agriculture and livestock farming. Consequently, land degradation, deforestation, desertification, overgrazing, lack of access to safe drinking water, and loss of biodiversity, compounded by climatic variability, become vital concerns that invariably must arise in the consideration of all conservation programs.

Therefore, in the creation of forest reserves, parks, and botanical gardens, the secret to their success must lie in the support and involvement of the local community. Unless the local people support them, few parks and reserves will survive for a long time. In the support zones of such parks and forest reserves, projects concerning agriculture, forestry (for fuel wood), fish farming and sustainable hunting should be introduced so that the local people may benefit directly from the project's activities. Furthermore, planned alternative sources of income to bush meat, such as cultivation of mushrooms, butterfly farming, husbandry of the cane rat and rabbits, and aquaculture should be established.

A growing body of research seems to be pointing toward the high worth of minor forest products like fiber, fruits, honey, and vegetables such as "eru," income from which when summed up often makes it more profitable not to destroy the forest. Education and awareness campaigns in this domain should be conducted in the local communities of the forest zones. Alternative forest-product industries also need to be developed. In Cameroon, for example, there are no processing industries for medicinal

plants; the future for this industry could be encouraging. The Korup Park project has demonstrated that the long-term benefits that accrue from tropical forest usage or exploitation are many more than simply the direct products harvested from the forest.

For conservation to be taken seriously in the whole country, it may be necessary to determine and locate the number of transient inhabitants of forest areas. They, too, must be brought into the conservation process and campaign; otherwise the local people of the forest areas will always be skeptical about the need and urgency of protecting forests and wildlife that they see being exploited to the benefit of outsiders. There is also the need to integrate the various organization interested in conservation in order to adopt a common approach to tackling the problems, without confusing the people. If people are to be persuaded not to use the forest in destructive ways, community-based development project alternatives must be provided.

REFERENCES

Declaration of National Population Policy. 1993. National Population Commission, Ministry of Plan and Regional Development, Haoude, Cameroon, March 1993.

Findings. 1997. Towards environmentally sustainable development in Sub-Saharan Africa. A World Bank Agenda, Report No. 1511-AFR.

Ndeso-Atangana, A. 1994. Directory of NGOs in Nature Resources Management Sector in Cameroon (unpublished).

Takwa, S. 1997. The World Wildlife Fund and its activities in Cameroon. The Herald, 453.

Takwa, S. 1997. Conserving the Kilum-Ijim Mountain forest. The Herald, 453.

USAID/Cameroon. 1983. Agriculture Sector Briefing Paper. Office of Agricultural and Rural Development.

SUSTAINABLE CONSERVATION BY THE CAMEROON ACTION PROGRAM

Amougou Akoa
University of Yaounde I, Faculty of Science
P.O. Box 812, Yaounde, Cameroon

SUMMARY

Cameroon is a country with a large variety of biomes and landscapes: steppes, savannas, lowland humid dense forests, highland forests, mangroves, and agrarian landscapes. Conservation policies and techniques put in place take into account the peculiarities of each ecosystem. The conservation of biodiversity is practiced at many levels. At the national level, conservation is focused on endemic species and genetic resources preservation as defined by the National Forestry Action Program. At the local level, conservation takes into account the respect, reinforcement, and development of local practices and traditions, while at the same time it considers the low social classes within the communities, the effective participation of rural populations in the planning, implementation, and benefits sharing of conservation programs. Since 1996, the Cameroonian forestry ecosystem has benefitted from criteria and indicators of sustainable management and research programs on genetic and biodiversity conservation.

INTRODUCTION

Cameroon is triangular in shape and has an area of 475,000 km^2. It extends from lat. 01°38' to 13°00' N, and long. 08°35' to 16°08' E. Cameroon stretches from the equatorial zone with an opening (more than 350 km of coast line) on the Atlantic Ocean to the (soudano-)sahelian zone. Thus, it has different types of natural landscapes that constitute its terrestrial ecosystems. From north to south, it contains: shrubby steppes (4,150,000 ha), wooded savannas (6 million ha), forested savannas (11.5 million ha), transition forests (8.5 million ha), semi-deciduous forests (9.5 million ha), evergreen forests (7.6 million ha) and mangrove forests (250,000 ha) (Figure 1).

These ecosystems enclose considerable floristic and faunistic diversity. From the floristic point of view, for example, Cameroon contains about: 7000 species of phanerogams of which 300 species are woody plants. This places Cameroon 4th in Africa behind Zaire (now the Democratic Republic of Congo), Tanzania, and Madagascar, in terms of biodiversity. Concerning fauna, there are: 542 species of fish with 96 endemic species, more than 15,000 species of butterflies, 850 species of birds of which 700 are resident and 250 are migratory, 250 species of mammals including the largest and the smallest known in the world, 165 species of reptiles of the 275 existing in Africa, 3 species of crocodiles, and 190–200 species of batrachians.

INSTITUTIONAL DISPOSITIONS FOR CONSERVATION

The 94/01 law

The new law no. 94/01, of 20 January 1994, on Forestry, Wildlife, and Fisheries Regulations implements chapter II for the protection of nature and biodiversity.

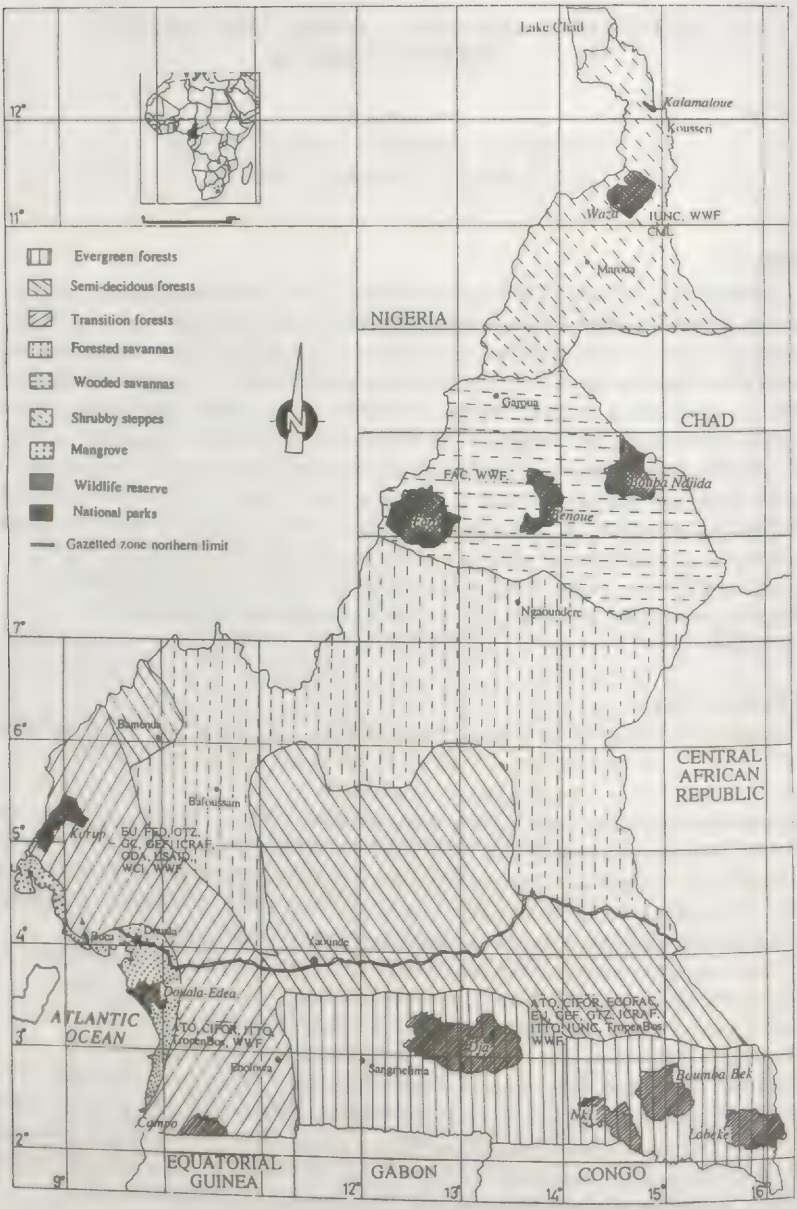


Figure 1. Phytogeographic map of Cameroon. Note the gazetted area of the South Cameroon forest with its northern limit about at the latitude 4° N, the protected areas (Korup), and GO and NGO zones of intervention (ATO, WWF) (adapted from Côté, 1993 and WWF/WCMC maps, 1996).

Articles 17, 18, and 19 of the law emphasize the will of the Cameroon government to conserve biodiversity and genetic resources.

The 94/01 law notably places emphasis on:

- genetic resources and biodiversity conservation methods (see conservation methods below);
- management of toxic substances and industrial wastes that can destroy or modify fauna and flora;
- sustainable forest management methods; and
- means of promotion and marketing of timber and other forest products.

The National Forestry Action Program (NAP)

The Ministry of the Environment and Forestry (MINE) together with the Ministries of Higher Education (MINUSES), Scientific Research (MINERS), Plan and Regional Development (MINT), National Education (MINED), Social and Women's Affairs (MANIOCS), Agriculture (MANAGER), Tourism (MINTER), and Territorial Administration (MINT) elaborated the National Forestry Action Program of Cameron (NFAP) in 1995. Broadly, with this NFAP, Cameroon wants to:

- ensure the protection of the forest heritage, participate in the safeguard of the environment, and preserve biodiversity in a sustainable manner;
- increase the participation of local populations in forest conservation and management in order to contribute to raising their living standards;
- develop forest resources with a view to increasing the contribution of forest production in the GDP while conserving the production potential;
- ensure resource renewal through regeneration and reforestation with a view to perpetuating the potential;
- revitalize the forestry sector by setting up an efficient institutional framework and involving all the concerning parties in the management of the sector.

To achieve these objectives, the NFAP has conceived many projects with various research themes that will be monitored: forest management (21 projects); rural forestry (17); remote sensing (5); industrial development (9); fauna and biodiversity (19); non-timber forest products valorization (5); and institutions reinforcement (6). Most of these projects focus on the biological diversity and genetic resources *in situ* and *ex situ* conservation.

CONSERVATION METHODS

The law and the NFAP cited above have identified two types of conservation.

In situ conservation

In situ conservation is done in protected areas that are natural habitats. These are ecosystems with all their essential functional components. These components include all the ecological interactions, in particular the symbiotic relationships and interdependent linkages within several food chains and trophic networks, and reproductive phenomenon through seed dispersal and pollination (FAO, 1994). All these interactions maintain species and population, i.e., genetic diversity.

One of the essential characteristics of the *in situ* conservation is, therefore, the fact that it ensures the continuation of evolution (Frankel, 1981). This means that genetic resources and their conservation are essentially dynamic, and that conservation

should not be considered as an attempt to preserve a defined and unchanging resource. At the same time conservation involves the avoidance of rapid erosion of genetic variability. For example, extinction of a population of a single species, or important changes in a given direction of the genetic composition of populations due to a drastic reduction of their numbers, can lead to enhanced genetic consanguinity or drift as a consequence of isolation (FAO, 1994).

Finally, *in situ* conservation involves wisdom in choosing options and values. In fact, there are many recent examples of species that were considered as not marketable or undesirable, and are now being sought (FAO, 1994). Furthermore, genetic resources conservation *in situ* could serve as biological material for genetic manipulation *ex situ* in order to determine their hereditary qualities and behavior in given environments.

In Cameroon, emphasis is being put on *in situ* conservation. In fact, the country still possesses many genetic potentialities as well as many endemic species within its natural ecosystems. In order to maximize the conservation of these biological and genetic diversities as well as endemic species, the Ministry of Environment and Forestry (MINEF) together with the MINPAT, MINAGRI, MINTOUR, MINMEE, MINUH, MINAT, MTPT, MINEPIA, and IRAD elaborated, since 1991, a land tenure system of the national territory. This land tenure system is an improvement of studies that began since 1960–1970 (Côté, 1993).

Concerning the tasks assigned to the conserved areas, the law of 1994 distinguishes many types (Côté, 1993):

- national parks. These cover an area of 806,000 ha. National parks are sites in which hunting, fishing, and gathering are regulated. They also have tourist uses.
- wildlife reserves are areas recognized as rich in faunistic diversity and in which hunting, and fishing are regulated.
- gathering reserves are forest areas rich in biological diversity and endemic species in which (except for hunting) one can harvest all non-timber forests products. These reserves represent a place of refuge for animal species within timber exploitation zones.
- integral ecological reserves, generally localized between two adjacent wildlife reserves, allow protection and movement of animals.
- protection forests are zones of fragile ecology whose role is to protect certain ecological functions. Hence, gallery forests and swampy sites, for example, are protected because of their role in the regulation of water regime. Mountainous sites are protected for their role in soil conservation and endemisms.
- teaching and research forests: areas conserved for carrying out practicals by pupils from general and technical high schools as well as implementation of research projects.
- recreation forests are sites managed for purposes such as walking, excursions, hikes, and other recreational uses.
- sanctuaries are sites recognized as rich in biological and genetic diversity as well as in endemic species and whose prime use is the protection of certain vulnerable and threatened plant and animal species. It is strictly prohibited to hunt or fish inside these areas.

Table 1 shows the surface areas allocated to each conserved area in the south forest zone of Cameroon.

Table 1. Distribution of surface areas according to land allocation of the national territory gazetted in the South Cameroon forest, for a total area of 14,011,127 ha (29.49% of the national territory) (Côté, 1993).

Conserved Areas Land allocation	Surface area (ha)	Percentage (%)
Teaching and research forests	34,351	0.25
Protection forests	557,590	4.12
Recreation forests	12,228	0.09
Sanctuary projects	23,539	0.17
Integral ecological reserves	235,393	1.68
Wildlife reserves	669,255	4.78
Wildlife reserve projects	715,782	5.11
Wildlife reserves/protection forests	29,915	0.21
Wildlife reserve/protection forest projects	12,361	0.09
Wildlife reserves/recreation forests	20,651	0.15
National parks	202,334	1.44
Area inhabited by man/National parks	23,910	0.17
Total of conservation areas	2,537,309	8.11

National Territory Gazetted Land allocation	Surface area (ha)	Percentage (%)
Production forests	6,024,608	43.00
Area inhabited by man	4,417,362	31.53
Food industry area and projects	95,797	0.69
Mining area and hydro-electricity projects	74,493	0.53
Community forests	275,213	1.96
Miscellaneous areas	566,545	4.04
Total national territory gazetted	14,011,127	100.00
Permanent Forests Estate (PFE)	8,983,571	64.12
PFE located in the private state estate	8,664,682	62.09

Ex situ conservation

Ex situ conservation techniques help to save some threatened species and races. Generally, this consists of creating botanical gardens, zoological parks, seed banks, and micro-organism and gene banks. In critical situations, domestication is used as a last resort to rescue threatened germplasm (Anon., 1993). The use of *ex situ* conservation is not yet very widespread in Cameroon because it is expensive. However, there is a desire by authorities to practice *ex situ* conservation technologies. Hence, a few conservation projects are still in the planning stages.

Botanical gardens The Limbe Botanic Garden is the only institution that is operational. It provides an intricate mosaic of a number of different habitats and communities that allow an exceptional concentration of avifauna. The presence of riverine, maritime, lowland forest, grassland, and gallery forest habitats occurring in a relatively small area also increases the probability of sighting many species. The Limbe Botanic Garden has the second-most important collection of Madagascar palms in the world, which also serves as a complementary collection to Madagascar. The collection

consists of the following genera: *Bismarckia* (1 species), *Chrysalidocarpus* (10 species), *Dypsis* (3 species), *Neophloga* (2 species, 1 subspecies), *Ravenea* (6 species). Plans include the enrichment of the garden in order to create a gene bank.

Zoological parks Renovation, rehabilitation, and creation of zoological parks constitutes the no. 73 project of the NFAP. Ongoing is the renovation and rehabilitation of the Limbe Zoological Garden. This zoo already houses 11 endemic primates including all the diurnal primates found on Mount Cameroon, and 5 endangered species: lowland gorilla (*Gorilla gorilla*), mandrill (*Mandrillus leucophaeus*), red-eared guenon (*Cercopithecus erythrotis*), preuss' guenon (*C. preussi*), and chimpanzee (*Pan troglodytes*).

Seed banks Agronomic Research Institute for Development (IRAD) has developed a seed bank in which seed of cultivated species are conserved.

Micro-organism strains The Department of Plant Biology of the University Yaounde I in collaboration with the Biotechnology Center of Nkolbisson are implementing a biofertilizer production and micro-organism conservation unit.

Captive breeding and management of species Projects nos. 24, 69, and 70 of NFAP are focused on the gene banks of guinea fowls, crocodiles, aulacaude, and ostrich, respectively. Projects nos. 61, 62, 63, and 64 elaborate and implement management plans for red-tail parrot, elephants, black rhinoceros, and all integrally protected animals in Cameroon. In the same NFAP, project no. 31 is planning for the introduction of pygeum (*Prunus africana*) into agrarian systems.

EXAMPLES OF PROTECTED AREAS

Taking into account the diversity of landscapes in Cameroon, zoning allocates several conservation areas according to vegetation types and relief (Figure 1).

Shrubby steppes zones: the Waza National Park (170,000 ha), considered a biosphere reserve of UNESCO, the Kalamaloue National Park (4000 ha), and the Gokoro, Mayo Bouto, Laf Madian, and Kalfou reserves.

Wooded savannas: the national parks of Faro (330,000 ha), Benoue (180,000 ha), and Bouba Ndjida (220,000 ha).

In the forested savannas, there are Mbembe, Fiba-Mahou, Manya Makombe, Santchou, Ngambouo, and Bafut Nguemba reserves. The Ngaoundere escarpment is an integral ecological reserve. The Adamaoua Province is considered as a sanctuary for the protection of hippopotamus.

Transition forests: the Nanga Eboko Wildlife Reserve (16,000 ha) and the Mbam and Djerem National Park (125,000 ha).

Semi-deciduous forests: the wildlife reserves of Boumba Bek (233,000 ha), Nki (200,000 ha), Lobeke Lake (450,000 ha); the Lopondji and Bom integral ecological reserves; the teaching and research forests of Pangar-Djerem of Bertoua (330,000 ha), Sangmelima and Mbalmayo; the recreation forests of Ayos, Yaounde-Ottotomo, and Edea; the Sikop gathering reserve near Edea (10,000 ha); the gorilla and chimpanzee sanctuaries of Mengame (near Oveng) and Sanaga Island bridge, respectively, and the Loungahe and Magambe reserves.

Low, middle, and high altitude evergreen rain forests: the Korup National Park (126,000 ha) considered as a biosphere reserve, the wildlife reserves of Dja (526,000 ha) set up as a world heritage site (Dec. 1987), Campo (270,000 ha), Ossa Lake (fowl reserve, 40,000 ha), the South Bakundu, Rumpi Hills, Mount Kupe (30,000 ha), Meme

Rivers, Mongoe Nkam, Tsena Nkam, Metche Goum, Nta Ali, Mawne River, Ejagham, Tokamanda, Fungam, Kimbi and Nkom, Wum, Kilum/Ijim (12,000 ha).

Mangrove and its neighboring areas: the wildlife reserve of Douala-Edea (100,000 ha) in the South of Wouri estuary; Mokolo River and Dibombe Mabobe.

The existence of all these areas, techniques, and projects shows that biological and genetic resource conservation is fully integrated in the government policy. The main problem is a chronic lack of staff, equipment, and infrastructure (Alpert, 1993). The Cameroon government cannot support the cost of conservation all alone. For example, the Ministry in charge of forestry has fewer than 300 forest guards who have to watch over all protected areas (more than 3,500,000 ha). That means there is one forest guard per 12,000 ha.

INTERNATIONAL COOPERATION

Agreements and conventions

Cameroon has signed many bilateral/multilateral, sub-regional/regional, and international agreements and conventions. These include:

Sub-regional conventions

- the 1964 agreement creating the Lake Chad Basin Commission;
- Lake Chad Basin agreement for wildlife management (Enugu, 3 December 1977);
- convention for cooperation concerning protection and management of marine and coastal zones of Western and Central Africa (Abidjan, 16 March 1981);
- cooperation agreement between Central Africa States on wildlife conservation (Libreville, 16 April 1983);
- African Timber Organization.

Continental conventions

- convention on the conservation of nature and natural resources;
- Bamako convention (31 January 1991) on waste exportation to Africa and the transboundary movement, transport, and management of dangerous waste.

International conventions

- convention on the protection of cultural and natural heritage (Paris, 23 November 1972);
- Vienna convention on ozone layer protection (Vienna, 22 March 1985);
- Montreal protocol on chlorofluorocarbon control (CFC) (Montreal, 16 Sept. 1987);
- convention on climatic change (14 June 1992);
- convention on desertification (Paris, October 1994);
- cooperation agreements with international NGOs (ITTO, ATO, etc.).

International technical assistance

In its efforts to conserve genetic and biological resources, Cameroon already receives technical assistance from many institutions (Anon., 1995). ECOFAC program (programme de Conservation et utilization rationale des écosystèmes forestiers en Afrique Centrale) is financed by the regional funds from the 6th EDF (European Development Funds). It is in keeping with the defined strategy from the Central Africa Regional Action Plan. The first step that began in 1992 concerns 7 countries:

- Cameroon, with the Dja wildlife reserve set aside as a world heritage site (576,000 ha);

- Congo, with 3 contiguous protected areas: national park of Odzala (126,000 ha), wildlife reserve of Lekoli-Pandaka (67,000 ha), and the hunting domain of Mboko (90,000 ha);
- Gabon, with the wildlife reserve of Lope;
- Equatorial Guinea with the national park of Monte Alen, on an irregular landscape;
- Central African Republic, with its N'gotto-Mbere Bodingue forest massive;
- Sao Tome y Principe, with its Zona Ecologica in the Center and the Southwest of the Sao Tome Island;
- and finally, Zaire, with the national park of Salonga (3,600,000 ha, about 50% of ECOFAC sites in terms of surface area). However, at present, no action has begun in this country because of diplomatic questions.

In addition to classical activities in a protected area, the program foresees the following thematic actions: improvement in fishing techniques; management of silviculture after forest exploitation; agroforestry and soil conservation; domestication of wild animals; participatory management of natural resources with the population; community tree plantations; harvest marketing of forest products; and tourism.

IUNC (World Union for Nature), thanks to the financial support of the Netherlands government, intervenes in the sustainable management of the wildlife reserve of Dja, which contains the following aspects:

- education and sensitization;
- eco-development with promotion and follow-up of agroforestry activities, small game breeding, consultation with timber operators, etc.;
- research in collaboration with local institutions to evaluate resources potential and harvest levels;
- reinforcement of state structures by providing logistics;
- local population integration and participation in conservation;
- research includes valorization and repercussion to authorities.

Another aspect of IUNC intervention involves elephant population management within the Waza park. The WWF support includes many domains. It oversees application and respect of several international conventions and treaties, including: the Convention on Biological Diversity, CITES (Convention on International Trade in Endangered Species), and the Ramsar Convention, which protects wetland zones. In the field, WWF runs many projects in different ecological zones throughout the territory. Within the steppe zone, Waza-Logone project is monitoring wetland restoration and the elephant population in Cameroon and Chad.

In the savanna zone, the Garoua fauna school projects offer fellowships on fauna and national parks; the rhinoceros project is engaged in managing rhinoceros in collaboration with FAC; the Mountain Survey Project and the Kilum and Jim Mountain Project are conducting surveys on mountainous ecosystems and endemisms; the Northern Savannas project inventories biodiversity and recruits and trains guards.

In the forest zone, the Korup Project supports the management of the Korup National Park; in the Boumba Bek, Nki, and Lobeke projects studies are conducted on protecting tropical rain forests. The Coastal and Marine Survey Project has implemented surveys in the littoral zone. GTZ, WCI, USAID EU, and FED contribute to sustainable management of Korup National Park.

ODA, via GTZ, has supported LBG management since 1988, as part of the Mount Cameroon Project. The Mount Cameroon Project is shown in Figure 2.

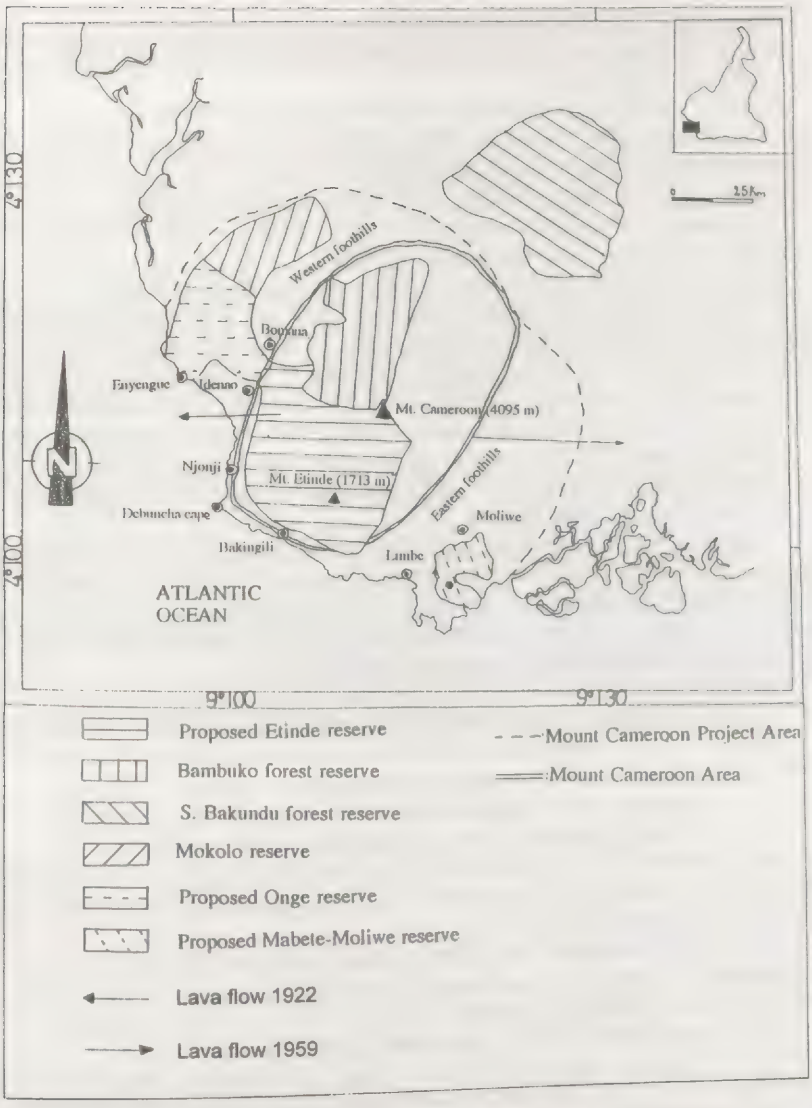


Figure 2. Details of the Mount Cameroon Project area. Note that Debuncha Cape is one of the most rainy zones of the world (more than 10,000 mm/year) (adapted from Anon., 1994).

This project concerns several areas (45,000 ha) and includes topics such as:

- the checklist of birds of the Limbe Botanic Garden;
- the ecology and conservation of tropical rain forests of Mount Cameroon;
- the botanical inventory of Mount Cameroon;
- the hunting and the wildlife survey in the proposed Etinde reserve;
- the anthropological study of people and forest use in Bowa I;

- the conservation of Madagascar palms;
- the Mount Cameroon Darwin project (seedling identification and forest regeneration and dynamics);
- the renovation and rehabilitation of Limbe Zoological Garden;
- timber exploitation "hot spots" in the Mabeta-Moliwe and Etinde proposed reserves and an assessment of preferred species;
- conservation through cultivation (LBG economic species project);
- the conservation and sustainable utilization of African botanical resources. A computerized checklist for Africa's vascular plants;
- the analysis of DNA sequences to evaluate angiosperm classification.

GEF/WB in the Netherlands, Tropenbos, GTZ, and WWF contribute to the sustainable conservation and management of Nki, Lobeke, and Campo reserves. BirdLife, ODA, EU, WWF, GC, and GEF contribute to the sustainable conservation and management of Mount Koupe. CIFOR, ITTO, ATO, and EU help in elaborating criteria and indicators of sustainable management through series of tests carried out as follows:

- from October 21 to November 17, 1996, in the littoral forest of Kribi;
- and from March 24 to April 17, 1997, in forests managed by communities in Endom region, near Akonolinga.

Tropenbos (tropical forests, in Dutch) is a research project with the objective of contributing to tropical rain forest management and conservation and to convince financial institutions to invest in forest research. In Cameroon, the Tropenbos research station is located in Kribi area (Southwestern Cameroon) within the evergreen forest zone. Tropenbos focuses its action on four domains:

- agronomy: soil evaluation, vegetation mapping, slash and burn agriculture;
- in ecology: biodiversity evaluation and conservation, plant-animal relationships;
- forestry sciences: silviculture, mycorrhizal studies, promotion of little known species, forest regeneration dynamics of exploited zones, less destructive and cost-effective exploitation methods, guidelines on southern forest management, and evaluation methods for impact of forest management on environment;
- social sciences involves: non-timber forest products inventories, Pygmy studies, traditional and modern legislation on forest products comparison, local populations' perception of forestry resources.

ICRAF (International Council for Research in Agroforestry), with its headquarters in Nairobi, Kenya, possesses a branch in Yaounde-Nkolbisson. This branch supervises the Humid Lowlands of the West African Research Program. Concerning conservation, ICRAF leads research activities under the theme "Multipurpose tree management and improvement." The specific activities include seed collection, establishment and management of some species' gene banks (*Irvingia gabonensis*, *Pausinystalia yohimbe*, *Prunus africana*, *Ricinodendron heudelotii*, etc.). The ultimate goal is to domesticate these plants and encourage artificial cultivation in areas where they are known to grow. The first species is used (fruits and seeds) as food, and the second is an important medicinal plant severely threatened by random and inappropriate methods of exploitation from the natural stock.

Many other governments and organizations (Great Britain, CIDA, UNDP, UNSO, FAC, etc.) are helping Cameroon to put in place an efficient conservation and sustainable management system to protect its biological and genetic diversity. In general, actions conducted by these NGOs and GOs remain very ill-defined and uncoordinated. They respond to the will of the financial backers whose policies can

sometimes be different from the goals of conservation and that of the host country. Some of these organizations demand territorial exclusivity for their works.

CONCLUSIONS

Cameroon, supported by the international community, makes efforts to conserve DNA resources *in vivo* either through its politics or through its action programs. Meanwhile, our country, constrained by the Adjustment Plan, does not have sufficient funds to ensure efficient conservation. The international community already helps our country in many ways, but this support remains inadequate considering the spatial expanse of natural conserved areas and the high costs of *ex situ* conservation techniques. In conclusion, the conservation of resources for sustainable management concerns everybody and every nation. Past errors and today's egoism must be surpassed in order to ensure that future generations will inherit natural ecosystems.

REFERENCES

Alpert, P. 1993. Conserving Biodiversity in Cameroon. Ambio 2(1): 44.

Anonyme. 1990–1993. "Directives de l'OIBT pour l'aménagement durable des forêts tropicales naturelles," OIBT Sér. tech. n° 5, Kuala Lumpur, Malaysia.

Anonyme. 1990. "Plan d'Action de l'OIBT (Organisation Internationale des Bois Tropicaux)." Critères et domaines d'action prioritaires régissant l'élaboration des programmemes et les activités de projet, 9e session, Conseil International des Bois Tropicaux, Yokohama, Japan.

Anonyme. 1992. "Le secteur forestier. Document de politique générale de la Banque Mondiale," Banque Mondiale, Washington, D.C.

Anonyme. 1994a. "Convention sur la biodiversité biologique." Textes et annexes, Unep/CBD, Suisse.

Anonyme. 1994b. "Le défi de l'aménagement durable des forêts. Quel avenir pour les forêts mondiales?" FAO, Rome.

Anonyme. 1994c. "Loi 94/01 du 20 Janvier 1994 portant Régime des Forêts, de la Faune et de la pêche," MINEF Infos, Edition hors série.

Anonyme. 1995. "Le plan d'Action Forestier Tropical," FAO/BIRD/WRI/PNUD.

Anonymous. 1992. "Global biodiversity: Status of the earth's living resources," Groombridge B., ed. Chapman & Hall, New York.

Anonymous. 1993. "African biodiversity: foundation for the future. A framework for integrating biodiversity conservation and sustainable development," WWF/The Nature Conservancy/USAID, Beltsville, Maryland.

Anonymous. 1994. Mount Cameroon Project. 1st Annual Science Review, T. Sunderland N. Ndam, eds. Limbe.

Anonymous. 1995a. Measuring and monitoring biodiversity in tropical and temperate forests, T.J.B. Boyle and B. Boontawee, eds. Jakarta, Indonesia.

Anonymous. 1995b. National forestry action programme of Cameroon. Forestry policy document, Ministry of Environment and Forestry. Yaounde.

Côté, S. 1993. "Plan de zonage du Cameroun forestier méridional. Objectif, méthodologie, plan de zonage préliminaire," Poulain Thériault Inc., Québec.

FAO. 1994. "Conservation des ressources génétiques dans l'aménagement des forêts tropicales. Principes et conepts," Etude FAO Forêts, 107.

Frankel, O.H. 1981. Evolution in jeopardy; the role of nature reserves. *In*: Evolution and Speciation, W.R. Atchley and D. Woodruff, eds., Cambridge University Press, Cambridge, UK.

Letouzey, R. 1968. "Etude phytogéographique du Cameroun," Paul Lechevalier, ed. Paris.

ACRONYMS

ATO	African Timber Organization
CIDA	Canadian International Development Agency
BirdLife	Bird Life International
CIFOR	Center for International Forestry Research
CITES	Convention on International Trade in Endangered Species
CML	Center of Environmental Science, Netherlands
ECOFAC	Programme Conservation et utilisation rationnelle des écosystèmes forestiers en Afrique Centrale
EU	European Union
FAC	Fonds d'Aide et de Coopération (French Development Agency)
FAO	Food and Agriculture Organisation of the United Nations
GEF	Global Environment Facility
GO	Governmental Organisation
GTZ	Gesellschaft für Teknische Zusamenarbeit (German Aid Agency)
ICRAF	International Council for Research in AgroForestry
IRAD	Agronomic Research Institute for Development
ITTO	International Tropical Timber Organization
IUNC	International Union for Nature Conservation
LBG	Limbe Botanic Garden
MINEPIA	Ministry of Livestock, Fisheries and Animal Husbandry
MINAGRI	Ministry of Agriculture
MINASCOF	Ministry of Social and Women's Affairs
MINAT	Ministry of Territorial Administration
MINCOM	Ministry of Communications
MINDIC	Ministry of Trade and Industrial Development
MINEF	Ministry of the Environment and Forestry
MINEFI	Ministry of the Economy and Finance
MINMEE	Ministry of Mines, Water Resources and Power
MINPAT	Ministry of the Plan and Regional Development
MINTOUR	Ministry of Tourism
MINTPT	Ministry of Public Works and Transport
MINUH	Ministère of Housing and Town Planning
ODA	Overseas Development Agency
ONADEF	National Forest Development Agency
NGO	Non Governmental Organization
GO	Governmental Organisation
SNV	Netherlands Development Organization
WB	World Bank
WCMC	World Conservation Monitoring Center
WWF	World Wildlife Fund

CASSAVA GERMPLASM COLLECTION AND CONSERVATION IN CAMEROON

Tumanteh J. Ambe and E. T. Awah
ESCaPP Cameroon,
Institute of Agricultural Research for Development (IRAD),
PMB 25, Buea, Cameroon

SUMMARY

The importance of cassava in the nutrition of many Cameroonians led to a nationwide intensive diagnostic survey. Cassava production constraints were identified to be addressed through research intervention technologies. The many varieties grown by farmers and the various reasons for growing different varieties motivated their collection, preservation, and protection. A total of 295 accessions were collected and established in the field for maintenance and preservation. Apart from the protection of the genetic resources base of cassava, the germplasm will provide the starting point for cassava plant improvement in the country. A documentary on the indigenous knowledge on cassava genetic diversity in Cameroon, the use of agrobiodiversity in traditional cultivars, and the participation of farmers in conservation work is provided.

INTRODUCTION

Cameroon is situated between latitudes 2° and 13° north of the equator and longitudes 8° and 16° east of the Greenwich Meridian. It covers an area of 475,926 km^2 (Ngwa, 1978). The country is divided into five major agroecological zones based on climate, land forms, and phytogeographic and soil factors (CNRCIP, 1981).

Cassava (*Manihot esculenta*, Crantz) is grown and eaten in all these eco-zones (Ambe, 1994). Cassava ranks first in terms of total production and consumption among the root and tuber crops such as: cassava, yams, sweet potatoes, cocoyams, and solanum potatoes grown and eaten in Cameroon (CNRCIP, 1981; Kamajou, 1989). Cassava is also the main crop in terms of per capita consumption in Africa (FAO, 1979).

Cassava growers in Cameroon are faced with many production constraints, which range from pests (diseases, insects, vertebrates, and weeds), soil and climatic factors, lack of improved agronomic practice, and slow dissemination of improved varieties, to long and short crop cycles. Pests and disease incidence and severity varied significantly with varieties across locations. Some varieties showed high resistance while some were very susceptible to both pests and disease. Vertebrate pests are reported as one of the major production constraints in all the ecozones. Some of the cassava varieties are not attacked by vertebrates presumably because of high cyanide content.

Over the years, farmers have acquired their planting materials from neighbors and markets and then moved them over long distances because of particular features or through research and/or extension services. Cassava is an open-pollinated crop; some varieties have been developed by open pollination in farmers' fields. Such varieties may have inherent genetic characteristics that warrant exploitation. This has been one of the factors responsible for the multiplicity of cassava varieties in farmers' fields.

The manner in which farmers harvest their crops and preserve the planting material for the next growing season leaves much to be desired. There is a high risk of losing valuable genetic resource materials that could be useful in the future, especially if farmers harvest during the off-planting seasons.

Breeding work always starts with existing genetic material. Broadening the base of genetic material for breeding increases the scope of plant improvement. There is, therefore, a necessity in preserving existing local genetic material for plant improvement.

The Ecologically Sustainable Cassava Plant Protection (ESCaPP) Project in Cameroon recently carried out a survey in the major cassava growing areas to identify the impact of seasonal changes on cassava production constraints (ESCaPP Cameroon, 1994). It was found that many local varieties are grown in the country. Some of these varieties have short growing cycles while others have long crop cycles of up to three years. Farmers carry out plant improvement by selection based on their desired qualities. Selected varieties are, therefore, grown for different purposes. These reasons include: early bulking; high fresh storage yields; resistance to pest and diseases; long ground storability of fresh storage roots; mealyness (good cooking ability); ease of transformation, and good market quality.

In areas where leaf consumption as vegetables was common, varieties with profuse branching and leaf production were adopted and found in every farm along with other varieties. Such varieties were usually planted very close to homesteads for easy access to the leaves for household consumption. Incidentally, even through biotechnology, all the parameters listed above cannot be put into one cassava variety at present. Therefore, farmers must grow more than one variety in order to satisfy their various needs.

Crop improvement has generally been based on breeding and selection. The principles are obvious, but the objectives change based on the biotic and abiotic environmental factors and the final use for the crop. Based on salient problems and the various uses of cassava identified in the field during a survey, germplasm collection, maintenance, characterization, and evaluation in the various cassava-growing regions becomes imperative. There has to be an inventory of the reasons why these different varieties are grown. Characterizations are made of their growth morphologies, fresh storage root yield, dry matter content determination, HCN content of leaves and storage roots, length of growth cycles, disease/insect pest incidence and severity, and mealyness. In achieving such an aim, the existing cassava varieties have to be protected through collection and maintenance.

The major goals of such a collection and maintenance scheme are:

- to conserve and protect the genetic resource of the local cassava gene pool from loss, which could eventually be exploited for meaningfully directed breeding purposes;
- to provide researchers with initial basic genetic materials for future research work on cassava; and
- to eventually provide the farmers with varieties that are adapted to their ecologies that are high yielding, stable, tolerant to prevalent pests and diseases, and satisfying to the consumers' taste through characterization, evaluation, and multi-locational testing for adaptation.

MATERIALS AND METHODS

An extensive diagnostic survey was carried out during the dry and wet seasons in 1994 within the central and West African sub-regions, involving four different countries: Ghana, Benin, Nigeria, and Cameroon, and within different agro-ecological zones, based on phytogeographic, landform, climatic, and soil factors. The sole aim was to alleviate hunger and poverty in the tropical countries by enhancing agricultural production while preserving the natural resource base. The research involved making an inventory of a farmer's production problems, developing, testing, and adapting intervention technologies, and strengthening the national plant protection capabilities. Four ecologies were identified in Cameroon for the survey: savanna highlands (zone I), humid rain forest (zone II), semi-humid rain forest (zone III), and Guinea savanna (zone IV). Each site/farm represented a surface area of 75 X 75 km. Sites were selected through validation, and the survey carried out through the use of questionnaires. A village focus group composed of men, women, and children was interviewed by a team of socioeconomists at each site to determine farmers' perceptions about cassava pests and production problems. Another team of plant protectionists and agronomists went into nearby cassava fields with some farmers.

In Cameroon, 61 sites chosen according to the intensity of cassava production were surveyed at the end of the dry season. Only 58 out of the 61 sites were revisited after the rainy season because of inaccessibility to three sites during the year. These sites fall within eight out of the ten provinces in Cameroon.

At each survey site, the focus group was asked to name and produce samples of cassava varieties grown in their village. From these samples, five cuttings of 20–30 cm were collected per variety for on-station establishment. The small number of cuttings collected per variety was necessary in order to reduce the burden on farmers who would bring only one stem of each variety from his/her farm and also to reduce the bulk of cassava stem cuttings to be transported the long distances that had to be covered. Varieties that could not be readily obtained were secured during the second season's survey.

Upon the return to the station after each survey, a nursery of 5 meter-long beds was established in which the collected cassava cuttings were planted for subsequent transfer to the field. Realizing the fact that cassava planting materials have been moved from village to village between farmers, different names might have been given to the same variety depending on the tribe's or village's attributes. Because of this discrepancy, all collected materials will now henceforth be call "accessions" until they have been characterized into varieties with common features.

In total, 315 accessions were collected and planted in a nursery of 5 meter-long ridges. This material was transferred into a field planted on two 10-meter ridges on-station in late 1995 and maintained for subsequent characterization and evaluation.

RESULTS

295 of the 315 accessions of cassava collected within the production zones in Cameroon have been established on 0.8 ha of land and on-station. The distribution of the collected cassava accessions per agro-ecozone were as follows: 31 from the highland savanna, 50 from the humid rain forest, 110 from the semi-humid rain forest, and 104 from the guinea savanna, respectively. Research proposals, including workplans, time

frames, and budgets have been prepared and sent to various donors/collaborating institutions, requesting funds to carry out the work on characterization and evaluation. While waiting for responses from these funding bodies and also looking forward for any collaborators in carrying out the work, the germplasm maintenance is in progress. The old field was cut down and replanted in 1997.

DISCUSSION

The variation in the number of accessions collected per agro-ecozone seems to be influenced by the different uses of cassava (Numfor and Ay, 1987). Cassava is most important in the semi-humid rain forest, followed by the guinea savanna, humid rain forest, and highland savannah agro-ecozones, respectively. The importance of cassava is also reflected in the number of accessions collected per agro-ecozone where the number increased with the number of ways cassava is used in the area (Numfor and Ay, 1987).

The collected and preserved cassava germplasm not only protects its genetic resource base in Cameroon, but also provides a starting point for research on cassava plant improvement in the country. The conservation activities of the plant genetic resources from the ecogeographic surveys provide documentation. Further analysis will reveal information about the indigenous knowledge on cassava genetic diversity in Cameroon.

The collection and preservation of local plant germplasm improves the use of agrobiodiversity in traditional cultivars and increases participation of farmers and communities in conservation work. By so doing, links are developed between communities and farmers in promoting collaboration between local groups and national institutions. Job avenues are also opened for the unemployed.

The collection of local cassava germplasm, which will provide ethnobotanical information, is part of the process of supporting the conservation of indigenous knowledge on plant genetic resources by the local communities that are the custodians of the genetic diversity of economically useful plants. Conservation, however, depends on how the material is used. In some cases, the uses are neither sustainable nor efficient, thus placing their conservation for future generations at risk. In other cases, formal research and development processes have ignored local and traditional uses of plant genetic resources that are both sustainable and add value to resources. Ethnobotany will, therefore, show how the uses of plant genetic resources affect the distribution of genetic diversity in agro-ecosystems and how social institutions can help maintain biodiversity. To further reduce risks of loss of locally conserved plant genetic resources, germplasm can be duplicated and conserved *in vitro* and can easily be moved between collaborating institutions without quarantine problems.

CONCLUSIONS

Plant genetic resource conservation is of paramount importance as a basis of plant improvement. It is also an assurance of continued plant varietal evolution through breeding procedures. In Cameroon, 295 cassava accessions have been collected and conserved. This will serve as the basis for future research work on cassava in Cameroon, providing growers with desired varieties that are adapted to local ecologies. National and international collaboration will be enhanced through exchange of genetic materials thereby broadening cassava genetic resource base for plant improvement.

ACKNOWLEDGMENTS

Our gratitude goes to the United Nations Development Program (UNDP) and the International Institute of Tropical Agriculture/Plant Health Management Division (IITA/PHMD) in Cotonou, through the Ecologically Sustainable Cassava Plant Protection (ESCaPP) project, for providing funds and technical support for the work to be done.

REFERENCES

Ambe, J. T. 1994. Effect of harvesting time on cassava fresh root yield in Cameroon. Discovery and Innovation 6(3): 315–317.

CNRCIP. 1981. Cameroon National Root Crops Improvement Programme, Annual Technical Report. IRA Njombe, B.P. 13 Njombe.

ESCaPP Cameroon. 1994. ESCaPP Cameroon dry season extensive survey summary report. IRA Ekona, PMB 25, Buea.

FAO. 1979. Production year book. Rome, Italy. 91: 93–99.

Kamajou, F. 1989. A socio-economic evaluation of the Gatsby Project in the CNRCIP of the Institute of Agronomic Research, Cameroon. B.P. 13, Njombe Cameroon.

Ngwa, J. A. 1978. A New Geography of Cameroon, Longman Group (FE) Ltd.

Numfor, F.A. and Ay, P. 1987. Post-harvest technologies of root and tuber crops in Cameroon. Memoires et Travaux de l'IRA No. 1.

THE CONSERVATION STATUS OF ZAMBIAN VEGETATION

M. G. Bingham
Consultant Ecologist
Private Bag 31, Woodlands
Lusaka, Zambia

SUMMARY

With a population of 9.3 million in an area of 752,614 km² and a moderate climate, Zambia is relatively well-endowed with land, water, and forest resources. Yet poverty in both urban and rural sectors results in heavy local demands being made on the woodlands, especially in the peri-urban areas. Estimates of the rate of deforestation are readily given when requested, but are based on guesswork. Such estimates are concerned with percentages without consideration of priority areas. Whereas woodland is fairly resilient, logging in the closed forests is destructive. Continued logging in some of the last deciduous forests of *Baikiaea plurijuga* (Zambezi teak or mukusi) is cause for concern. Recent logging of *Daniellia alsteeniana* in the Luapula Province has caught the authorities unawares, and with limited resources there is little they can do about it.

There is an urgent need for a program to monitor forest products, which are increasingly being harvested for commerce. These include not only timber trees, but the host trees of edible caterpillars. These trees are felled for ease of harvest of caterpillars, fiber plants, and edible orchid tubers. The preference of donors to support large projects results in the neglect of support for monitoring, which requires flexibility rather than large budgets.

INTRODUCTION

Zambia is centrally situated in the Zambezian Regional Center of Endemism (White, 1983). Topographically it consists mostly of flat, high-level plateau, ranging in altitude from 1000 m to 1600 m, transected by several downfaulted troughs, the southernmost extension of the East African rift valley system. A few mountain peaks in the northeast rise above 2000 m.

The plateaus are traversed by large rivers arising along the continental divide, which runs from west to east, from the source of the Zambezi in the northwest, to the source of the Luangwa in the northeast. Many of the major rivers have extensive floodplains. The western part of the country is blanketed with aeolian kalahari sand.

The major vegetation type of the region is miombo woodland, which dominates the well-drained plateaus and escarpment slopes. Miombo is a fire-climax type with a rich and varied ground cover. Drainage is mostly provided by flat-bottomed depressions (dambos), which are generally treeless. The miombo and associated dambos form a stable system which is fairly resilient to abuse. Permanent deforestation, which is usually associated with cultivation, can cause serious disturbance to the hydrology, leading to degenerative changes to the soil and vegetation (McFarlane and Whitlow, 1990).

CENTERS OF ENDEMISM

Main centers of endemism tend to be situated along the borders with Zaire, Malawi, and Zimbabwe. Thus, Zambia as a country has few true endemics, but shares several

important areas of endemism with these neighbors. Among the most important are the area around the source of the Zambezi (Bingham, 1994); the Bangweulu Basin; the Itigi thickets between Lakes Mweru and Tanganyika, and the general area surrounding them; the montane areas on the border with Malawi; the Zambezi Valley and its escarpments; and the kalahari sands of western Zambia and adjacent areas in neighboring countries.

VEGETATION SURVEYS

The vegetation of Zambia has been classified by Trapnell (1959), Rattray and Wild (1961), White (1968), and Fanshawe (1971), and mapped by Rattray and Wild (1961) and Edmonds (1976). Emphasis has been on the woody vegetation. Rattray's map (1957) of the grassland of Zimbabwe has some relevance. Van Rensburg (1968), Rees (1978), and Ellenbroek (1980) all published accounts of the ecology of the Kafue Flats. Recently, more detailed vegetation maps have been published of the vegetation of Western Province (Barotseland) by Jeanes and Baars (1991) and Baars (1996). Phiri (1989) has compiled an annotated checklist of the flora of the Luangwa Valley (South) (to be published in Kirkia).

The whole country was covered by aerial surveys at scales ranging from 1:20,000 to 1:40,000 in the 1960s. Many areas have been reflown; the air photo library in the survey department has a good series for many parts of the country. However, many of the more sensitive and species rich areas of marginal economic interest have not been reflown, and, more seriously, some of the negatives from the original surveys have been lost. Digitized mapping of some of the national parks and game management areas has been carried out, and a digitized survey of watering points has been carried out in all rural areas.

In spite of the availability of good air photo surveys, very little use has been made of this collection to assess changes in woody plant cover. For example, Dowsett-Lemaire (1985) and others have referred to the destruction of submontane forest on the Zambian Nyika by uncontrolled fires. Comparison of two aerial surveys (August 1966 and September 1982) do not support this observation. While the double firebreaks ceased to be maintained soon after independence (1964) and the Department of National Parks and Wildlife Service maintained no permanent staff in the Nyika National Park during that period, there is no evidence of attrition at the forest margins of the Manyenjere forest. In fact there was a distinct increase in the woody component of the surrounding vegetation (the Chowo Forest, on the southern side of the Chire Valley was obscured by cloud in the 1960 survey). More recent attempts to rephotograph the Zambian Nyika have been frustrated by cloud cover.

DROUGHT AND FROST

There has been much damage to the natural vegetation in southern Zambia in recent years from a combination of drought and frost. The valuable fruit tree *Uapaca kirkiana* has been particularly affected. Mature miombo woodland has also been affected, with many of the canopy dominants being killed by drought, particularly in 1993. Fierce fires frequently follow destruction by both drought and frost, as the result of the accumulation of tinder and exceptionally hot and dry conditions during the subsequent dry season.

FIRE AND FUELWOOD HARVESTING

The catastrophic fire that swept through the famous woodland burning plots at Ndola in October 1987, wiping out one of the most valuable experiments in tropical Africa, could perhaps be blamed on inadequate management. Yet, the Forest Department had succeeded in keeping fire out of the fire-protected plots since they were established in 1933. In spite of enormous difficulties, the situation was made worse by gross underfunding after independence and illegal firewood collecting. In fact, the October 1987 fire can be regarded as the end of one regime and the start of another, something which happens all the time in nature.

DEFORESTATION

Fuelwood gatherers and charcoal producers receive much criticism for deforestation, and it is indeed sad to see large areas of miombo woodland cut. Yet tree-cutting is not necessarily permanently damaging, and can even have a beneficial rejuvenating effect on the vegetation. Repeated cutting of the coppice leads to a degenerate scrub vegetation, which is inevitable in peri-urban areas to which fuelwood gatherers have access. Increased grass cover after tree-cutting results in more destructive fires; this happens mostly on the deeper soils, which have an arable potential.

With the steep rise in the urban populations since independence, edible caterpillars have become a protein staple. Commercial harvesting has replaced traditional methods. Operators from urban centers employ local people to cut the host trees (*Julbernardia paniculata* mostly) for easy harvesting. Woodland clearance for cultivation deprives the insect of its habitat; the female moth is able to fly only a short distance, and cannot cross cleared fields. The most accessible remaining habitats are PFAs. Neither the Forest Department nor the local chiefs are able to stop or control the harvesting.

AGRICULTURE

Agriculture accounts for far more destruction of the natural vegetation than any other factor. Moderate levels of disturbance promotes species richness, but agriculture frequently destroys the natural vegetation completely and permanently. A vivid demonstration of the change can be seen in areas near Mapanza in Southern Province, settled in the 1960s through one of the Department of Agriculture's resettlement programs. Rectangular fields were surveyed, leaving woodland shelter belts between adjacent fields. The vegetation of fallow fields consists of species such as *Acacia polyacantha*, *Faidherbia albida,* and *Borassus aethiopum*; the shelter belts still have the miombo canopy of *Brachystegia spiciformis,* but the understory is heavily invaded by the scandent *Bauhinia petersiana*. The area described is an ideal rural settlement. In most of the resettlement farming areas, the shelter belts have long since disappeared or been replaced by weedy species.

Many commercial farmers are conservation conscious, but few have sufficient understanding of woodland ecology to apply appropriate management. Tobacco is the most important export crop of the region. Most of the tobacco grown in the past was Virginia, which requires flue curing. Miombo woodland provided the fuel, and the sale of tobacco paid the clearing cost of converting miombo into arable land for maize cultivation or for pasture.

Many farmers now regret the loss of their miombo. Very few have been successful in establishing eucalyptus plantations. The collapse of the forest nurseries and the

extension service, just at the time when they were most needed, was unfortunate. The closure of the border with Rhodesia, for political reasons, made it difficult for Zambian commercial farmers to benefit from research and services that were much better developed than their Zambian counterparts.

SENSITIVE PLANTS

Sensitive and vulnerable plant species provide the best indicators of the conservation status of the habitat as a whole. Fire-sensitive trees and shrubs survive mostly in thicket patches, on steep rocky slopes, or on termite mounds. Shallow soils overlying laterite pavements provide a habitat for thickets. Freely draining sandy soils are also favorable to woody species, and some of the most productive forests occur on the aeolian kalahari sands of western Zambia.

In miombo woodland the presence of milkweeds (*Asclepiadaceae*) and orchids, both terrestrial and epiphytic, are indicators of well-being. Miombo milkweeds and terrestrial orchids all have perennial storage organs from which annual shoots arise. Growth occurs mostly during the rainy season, which is the only time of the year when the miombo grasses are palatable to cattle. Miombo pastures inevitably lose their milkweeds and orchids, which are replaced by a great variety of pasture weeds. Like all miombo woodland herbs, the milkweeds and orchids are fire-adapted. The exclusion of fire is likely to favor woody species, which will shade out the herbaceous flora.

Tubers, known as chikanda, of terrestrial orchids are harvested, processed, and sold in urban markets. Little is known about the species used or their conservation status. Like many traditional bush foods, chikanda have become commercialized in response to the rapidly expanding urban demand. Epiphytic orchids are much less common in the drier south, with annual rainfall from 600–1000 mm, than in the north in the higher rainfall areas. They frequently occur on trees that are on the decline, with thinning canopies. Such trees are particularly susceptible to drought, and, when host trees die, the epiphytes die with them. Yet orchids, with their spore-like seeds, are highly mobile and seem able to survive in scattered and isolated habitats.

ALIENS

Zambia has fewer problem species than most other countries, partly because there has been less disturbance. Commercial agriculture was on a very limited scale until the 1950s. That is not to deny that many poorly managed cattle ranches have serious weed problems. *Lantana camara* has taken over large areas of commercial pasture on some ranches, and it is a nuisance in residential areas where it invades hedges. Recent droughts seem to have set it back.

At times it appeared as though *Acacia karroo* (generally regarded as indigenous to Zambia, but this is doubtful), *Solanum mauritianum* (bugweed), and *Chromolaena odorata* would inundate Lusaka, but a succession of drought years, culminating in the 1995 season when watertables dropped to unprecedented levels, saw them retreat into the refugia of urban gardens.

The current obsession among donors and their beneficiaries with agroforestry and tree planting has fortunately not come up with a "miracle tree" that competes successfully with our local Acacias and Brachystegias. This is certainly not due to lack of effort. Nonetheless, one or two introductions need to be watched. *Toona ciliata* is a nuisance in urban areas, where it is a popular street and garden tree. It also invades riverine fringing

forest and could displace indigenous species. *Maesopsis eminii*, indigenous to Uganda, was planted in timber trials at Ndola, and was also planted as a street tree. Dispersed by man, birds, and bats, it has spread into prime woodland and riverine forest in Copperbelt and Luapula Provinces.

RESERVED AREAS

Three categories of land designated for nature reserves need to be considered, and also private game ranches, which, although not reserved areas, have an important role to play in conservation.

National Parks and Game Management Areas (GMAs)

The national parks and GMAs fall under the Department of National Parks and Wildlife Service. The management of the parks is directed primarily toward wildlife conservation. The GMAs are the buffer zones surrounding the parks where controlled hunting is permitted.

Because safari hunting is one of the most lucrative of rural industries, the GMAs are planned to be self-supporting as well as contribute substantially to the running of the department and the parks. The ADMADE Program, initiated in 1984, is implementing communal management of the wildlife resources. There are plans to include the forest resources within the communal management program, but this has been slow in coming, partly because of the slow pace of the required legal reforms.

Wildlife conservation is not always in harmony with environmental protection. South Luangwa National Park is Zambia's most popular tourist park and certainly one of the best in Africa. The concentration of animals, especially elephant and hippo, along the riverine alluvium is not sustainable, and, of all the major rivers in the country, the Luangwa is the only one that carries substantial quantities of soil.

Culling within the national parks is a controversial issue arousing much emotion within the conservation minded, particularly in the case of elephant. Elephant have destroyed most of the best mopane woodland in the Luangwa and Zambezi valleys, yet there has been no public outcry. During recent droughts elephants have resorted to tearing the baobabs apart. Again, the public is more concerned about elephants than the baobabs.

Private Game Ranches

Private game ranches are a major industry in South Africa, Zimbabwe, and Kenya. In Zambia they got off to a slow start, after much consideration by the government. Game ranchers have certainly had great success in breeding animals. Zambian game ranches are mostly too small in area to support a ecologically balanced system. However, there are vast tracts of suitable land available; when the investment prospects improve, there is little doubt that the investors will come.

Private game ranches are not ideal for conservation of natural vegetation types. Ranchers naturally want to optimize the more valuable species. Replacing cattle with a variety of herbivores is certainly an improvement, but carnivores tend to be regarded as vermin, and stocking rates are generally far in excess of the natural capacity, particularly in miombo woodland areas.

Protected Forest Areas (PFAs)

There is much public misunderstanding of the intended function of PFAs. The Forest Act establishes two kinds of PFAs: the national forests and local forests. National forests include designated areas for the protection of watersheds or other areas of national importance, such as the teak forests of Sesheke, Senanga, and Kalomo districts in the southwest part of the country. Large areas of national forest in the Copperbelt Province were set aside for timber plantations.

The exploitation of the national forests is at the discretion of the chief conservator, and any royalties accrue to the national treasury. There is no stipulation that any forest is exempt from logging, although the Ministry may legislate a statutory instrument to this effect.

At the time PFAs were gazetted, there were few people living in them, and in most cases these people were persuaded to relocate. This was not always the case, however, and a number of national forests have settled populations, although it is still government policy that they should be resettled out of the areas. There have been cases of schools being built with donor funding within forest areas. The Forest Department, underfunded and criticized for not allowing free access to PFAs, had long since given up the struggle to defend its territory. With the promotion of communal management, the prospects of allowing settlement within PFAs is being reconsidered.

Botanical Reserves and Natural Heritage Sites

In his submission to the Symposium on Conservation of Vegetation in Africa South of the Sahara (Hedberg, 1968), Frank White lists various categories of reserve land. Apart from PFAs, a large number of botanical reserves were selected and recommended for special protection by the Forest Department. Many other areas of natural interest were listed by the Natural and Historical Monuments Commission.

No legislation was ever passed to give protection of the Forest Department's botanical reserves. The boundaries were never surveyed and demarcated, and many of those in the peri-urban areas were cut for charcoal production, or cleared for cultivation.

The national heritage sites (as they are now known) have fared better. The National Heritage Conservation Commission (NHCC), which replaced the Monuments Commission, headquartered in Livingstone, has more effective legal status, and has been far more active than the old commission ever was. It has been instrumental in getting the major heritage sites surveyed, and employs guards to take care of them.

The 13 natural sites designated National Natural Monuments include waterfalls (but not Victoria Falls, a World Heritage Site), lakes, the source of the Zambezi River, etc. There is also legal provision to register any sites of natural interest as natural monuments (Shalwindi, 1996).

In the present situation the NHCC provides the best prospect for *in situ* conservation of natural vegetation, at least in the public sector. With the extensive revision of the Forest Act, now in progress, it is possible that the Forest Department (or whatever body is to succeed it) will play a more active role in conservation.

REFERENCES

Baars, R. M. T. 1996. Condition and management of the rangelands in the Western Province of Zambia. Ph.D. thesis, Wageningen Agricultural Univ.

Bingham, M. G. 1994. Zambezi source area. *In:* "Centres of Plant Diversity. A Guide and Strategy for their Conservation," S. D. Davis et al., eds. WWF, IUCN.

Dowsett-Lemaire, F. 1985. The forest vegetation of the Nyika Plateau (Malawi-Zambia): ecological and phenological studies. Bull. Jard. Bot. Nat. Belg./Bull. Nat. Plantetuin Belg. 55(3/4): 301–392.

Edmonds, A. C. R. 1976. Vegetation map of Zambia. 1:500,000, 9 sheets. Forest Department and Federal Republic of Germany.

Ellenbroek, G. A. 1980. Ecology of the Kafue Flats. *In*: DHV, Kafue Flats hydrological studies. Final report, Amersfoort.

Fanshawe, D. B. 1971. The Vegetation of Zambia. Division of Forest Research, Kitwe.

Hedberg, I. and O. 1968. Conservation of vegetation in Africa south of the Sahara. Proceedings of a symposium held at the 6th Plenary meeting of AETFAT in Uppsala, Sept. 12–16, 1966. Acta Phytogeographica Suecica 54.

Jeanes, K. W. and Baars, R. M. T. 1991. The vegetation ecology and rangeland resources, Western Province of Zambia. RDP Livestock Services, Zeist, The Netherlands.

McFarlane, M. J. and Whitlow, R. 1990. Key factors affecting the initiation and progress of gulleying in dambos in parts of Zimbabwe and Malawi. Land Degradation and Rehabilitation 2: 215–235.

Phiri, P. S. M. 1989. The flora of the Luangwa Valley and an analysis of its phytogeographic affinities. Ph.D. thesis, Univ. of Reading.

Rattray, J. M. 1957. The grasses and grass associations of Southern Rhodesia. Rhod. Agric. Journ. 54(3): 197–234.

Rattray, J. M. and Wild, H. 1961. Vegetation Map of the Federation of Rhodesia and Nyasaland. Kirkia 2: 94–104.

Rees, W. A. 1978. The ecology of the Kafue lechwe. J. Appl. Ecol.15: 163–217.

Shalwindi, F. K. M. 1996. Zambia's natural monuments. Zambia Heritage No.8, Aug.

Trapnell, C. G. 1959. Ecological results of woodland burning experiments in Northern Rhodesia. J. Ecol. 47: 129–168.

Trapnell, C. G., Friend, M. T., Chamberlain, G. T. and Birch, H. F. 1976. The effects of fire and termites on a Zambian woodland soil. J. Ecol. 64: 577–588.

Van Rensburg, H. J. 1968. FAO multipurpose survey of the Kafue River Basin, Zambia. Vol. IV, Ecology of the Kafue Flats. Rome, FAO. 316 pp., 199 plates, 14 maps, 53 drawings.

White, F. 1968. Zambia. *In*: Conservation of Vegetation in Africa-South of the Sahara. I. and O. Hedberg, eds. Acta Phytogeographica Suecica 54: 208–215.

White, F. 1983. The Vegetation of Africa. A descriptive memoir to accompany the Unesco/AETFAT/UNSO vegetation map of Africa. UNESCO, Paris.

Editors' note: The following article was presented at the DNA Bank-Net III meeting by Mike Bingham and was of such interest that we have asked him to allow us to append it to this chapter.

THE CONSERVATION STATUS OF ZAMBIAN VEGETATION A CASE HISTORY: THE BAIKIAEA FORESTS

M. G. Bingham

In 1903 the rail bridge over the gorge below Victoria Falls was completed, as part of Cecil John Rhodes's ambition to build a railway from Cape Town to Cairo. This railway, and indeed much of the railway system of southern Africa, was made possible by the exploitation of the vast resources of hardwood timber in the area where five countries come together: Angola, Zambia, Zimbabwe, Botswana, and Namibia. The timber, then known as Rhodesian teak, and now as Zambezi teak (Piearce, 1986), was derived from the leguminous tree *Baikiaea plurijuga* Harms, which grows on aeolian sands of the Kalahari system within rainfall limits of about 600–1000 mm. The tree is a constituent of two distinct vegetation types, a deciduous thicket (Mutemwa) and Kalahari woodland. The best trees occurred in forest, which did not normally burn in their undisturbed condition. In contrast the woodlands are frequently burnt, and most of the trees have fire damage at the base of the bole, which reduces the value of the timber.

Large orders by Rhodesia Railways for sleepers in the 1920s led to the extension of logging operations to the extensive forests of Sesheke and Mulobezi, where the best forests occurred. Production peaked at about 100,000 m² from 1938–40, and again in 1965. Since then there has been a steady decline in production, to about 20,000 m² in 1972, when Zambezi Sawmills, the major producer, was taken over by government as the sole owner.

Attempts by government to control logging by more sustainable methods was instituted in the 1930s. When Zambezi Sawmills secured the concession on the Machili forests in 1926, the only management clause required them to fire-protect the cutting area. From 1931, when Forest Officer J. D. Martin was posted to Machili, a protracted battle started between Zambezi Sawmills and the Forest Department (FD), which wished to implement more sustainable logging and management procedures. Martin proposed the restriction of logging to the best stocked areas and to trees of a minimal girth, the removal of debris, fire protection of the whole concession area, and spot sowing of not less than 100 acres of mukusi. He also urged a significant increase of the royalty paid to the Litunga, the paramount chief of Barotseland.

The baikiaea forests are particularly susceptible to fire. In a normal year no rain falls for a period of 8 months. Before the first significant rains, usually toward the end of November, the risk of fire is great. In fact, the existence of the baikiaea forest is little short of a miracle, and is yet to be satisfactorily explained.

At the time of Zambian independence (1964) there were five fire towers in operation in Sesheke District. When I first visited the area in 1991, the only machinery in working order at Masese, the main field station, either belonged to or was maintained by a Dutch-funded agricultural project. Even the fuel to pump water was provided by the Dutch project. Firebreaks had not been maintained for years. Grass grew rank in the firebreaks, which served as fire conduits. In any case the FD had no functional fire-

fighting equipment. Some months before my visit FD personnel had attended a meeting where it was resolved to establish Managed Resource Areas, which were also to serve as seed banks, for the more important indigenous timber species. As a result, two sites in the teak forests were selected, demarcated, and given the recommended treatment. This required the clearing of the thicket and secondary tree species, and enrichment planting with baikiaea and *Leucaena*. I believe the purpose of the *Leucaena* was to tempt the large resident population of duiker (antelope), in the hope that they would desist from browsing the growing tips of the baikiaea seedlings.

The thicket was slashed by contract labor, but the tractor, which was meant to drag out the brushwood, broke down and could not be repaired before the hot dry season. Nor were there funds to employ people to do the job. I have not seen mention of the fire that destroyed this plot and some of the surrounding forest in any FD reports. (Nor was the destruction by fire, in October 1987, of the famous Ndola Woodland Burning Experiments, established in 1933, given any publicity.)

The baikiaea forests produce a good seed crop in most years, but if any seedlings survive the first dry season, they are invariably killed off before the second one. We know why they die, or at least we know of many contributory causes. What we have not discovered is how to grow baikiaea in plantations; there are very few plantings that show even a slight promise. Even the maintenance of the few remaining undisturbed forests has been difficult during recent periods of drought. Yet timber concessionaires are required to "resow" in the areas they harvest. To meet this requirement the FD devised a simple expedient. They supply the concessionaires with baikiaea seed to be scattered into the fire holes. This may be seen as cynicism on the part of FD, but what else can they do in the circumstances? If the funding agents and conservationists, and, indeed, the politicians, want quick fixes, but are not prepared to invest in long-term research projects, that is the sort of response we should expect.

Recently a Japanese (JICA) team carried out a 2-year inventory of the former prime forest areas of Mulobezi and Sesheke and found all forests to be depleted if not completely destroyed. In 1993 the FD and GTZ commissioned an appraisal for a project aimed at sustainable management. This project is now approaching the end of its inception phase. The problems it is facing are daunting. When Zambezi Sawmills was in full production it employed about 2000 people. Most of these people and their descendants have remained in the area as subsistence farmers. They keep a few cattle and practice slash-and-burn cultivation. The farmers want to clear the remaining forests for cultivation, and the FD is under strong pressure to release forest reserves, which it does not have the resources to protect.

The donors are now trying to establish a system of monitoring, particularly in the forestry and wildlife sectors, by independent teams. This is being strongly resisted by the departments concerned, who expect little sympathy from the consultants and NGOs with whom they have worked in the past. It seems there might be a compromise in the newly fledged Environmental Council. The ECZ inspectors are inexperienced and need strong technical and legal support.

REFERENCES

Piearce, G.D. 1986. The Zambezi Teak Forests. Proceedings of the First International Conference of the Teak Forests of Southern Africa, held in Livingstone, Zambia, March 1984. The Forest Department, Ndola, Zambia, in cooperation with FINNIDA/VTT Tech.

THE CONSERVATION OF GERMPLASM OF AGRICULTURAL PLANTS IN SOUTH AFRICA WITH PARTICULAR REFERENCE TO VEGETABLES, POTATOES, AND CASSAVA

Joe J. B. van Zijl
ARC-Roodeplaat Vegetable and Ornamental Plant Institute
Private Bag X293, Pretoria, 0001, South Africa

and Rihana Botha
ARC-PGRU, Private Bag X05
Lynn East, 0039, South Africa

SUMMARY

Eight institutes of the Agricultural Research Council (ARC) are responsible for a germplasm collection of 36,321 accessions of plant species important to agriculture. Information regarding the number of accessions held in each crop group is given for each institute. The vegetable, potato, sweet potato, and cassava collections of ARC-Roodeplaat Vegetable and Ornamental Plant Institute are discussed in more detail. Germplasm of conventional vegetable crops is maintained as a seed collection. Certain landrace cultivars and open-pollinated cultivars have been maintained to supply breeder seed for the production of certified seed by the vegetable industry. Attention is being given to expanding and characterizing the collection of traditional vegetables. Potato, sweet potato, and cassava accessions are maintained disease and virus free *in vitro*. Sweet potato accessions from the International Potato Center (CIP) and cassava accessions from the International Institute for Tropical Agriculture (IITA) required for the South African Regional Root Crop Networks (SARRNETT) research program are also held. The potato and sweet potato collections have been characterized and evaluated. *In vitro* potatoes are supplied to laboratories for the production of planting material. Extensive precautions are taken to ensure that material supplied is disease free. Nuclear material required to supply the disease-free sweet potato planting material scheme is obtained from a collection held in a glasshouse.

INTRODUCTION

Germplasm of agricultural plants in South Africa is largely conserved *ex situ* by the Agricultural Research Council of South Africa (ARC) and to a lesser extent by the National Department of Agriculture and other institutions. The ARC is engaged in research, development, and technology transfer. It has 8 Plant Science Institutes, 5 Animal Science Institutes, 3 Specialist Institutes, and a Plant Genetic Resources Unit (ARC-PGRU). The research capacity consists of a network of experimental farms, modern equipment, and staff of approximately 4150 people, including 710 professional researchers and 612 technologists.

The ARC-PGRU ensures that the plant genetic resources (PGR) policy of the ARC is compatible with national, regional, and global initiatives on conservation. It represents the ARC on all relevant forums to see that national agricultural interests are considered in all PGR-related policies and strategies. The ARC-PGRU takes steps to achieve long-term, secure conservation of PGR collections of crops with orthodox seed, recalcitrant seeds, and vegetatively propagating species in conventional genebanks, *in vitro* collections, and field genebanks. It encourages the characterization, utilization,

and availability of these collections for use in the ARC, South Africa, regionally, and internationally. The ARC-PGRU strives to maximize the realization of financial benefits from commercial exploitation of the indigenous and traditional crop genetic resources of the Republic of South Africa (RSA) and to ensure that these benefits are equitably shared with relevant communities and farmers.

The ARC-PGRU acts as a coordinating body in respect to the germplasm activities and collections that are housed at ARC institutes. It rationalizes PGR collecting activities within the ARC for more effective accession of germplasm. It also coordinates these activities with those of the South African National Plant Genetic Resources Center (NPGRC) under the National Department of Agriculture, the Southern African Development Community (SADC), Plant Genetic Resource Center (SPGRC), and the International Plant Genetic Resources Institute (IPGRI). ARC-PGRU also provides support services to ARC institutes in order to integrate ARC-PGR activities with International and SADC policies to ensure continued international transfer of germplasm. It develops and implements new techniques related to genetic resource management and facilitates the documentation of all ARC-PGR material in a standardized and compatible system.

The ARC institutes have built up substantial collections of germplasm to support their active breeding programs. Except for ARC-Roodeplaat and ARC-RFI, these collections are comprised largely of germplasm of imported exotic agricultural crops and crop relatives. In addition they constitute active rather than base collections, and in some instances the material is not maintained beyond the point at which it is no longer required in breeding programs. In other words these collections, though quite substantial, do not fulfill the criteria of base repositories of germplasm being stored for long-term conservation, strategic, or food security purposes (Moss, 1994).

ARC GERMPLASM COLLECTIONS

Eight of the 16 ARC institutes are responsible for the conservation of 36,319 accessions from species belonging to crop groups that are of importance to agriculture (Table 1). The institutes are located in many different regions of South Africa. These germplasm collections originated from the need to conserve genetic resources, particularly material resistant to diseases, and pests to be used in breeding programs as well as lines and cultivars bred. Most of these collections have been built up over many years and are also used to supply the respective industries with true to type disease-free seed of open-pollinated cultivars. Valuable locally adapted landraces and adapted cultivars and lines of the major agricultural crops are conserved.

The main activities and mandate crops of the eight ARC Institutes involved with PGR programs are:

ARC-Grain Crops Institute (ARC-GCI)

ARC-GCI research emphasis is on sustainable agriculture and food security, the ability to maintain and increase food production without damaging or depleting the natural resource base. Research programs are divided into summer grain research and oil and protein seed research. Summer grain research concentrates on South Africa's major summer grain crop, maize, as well as sorghum and millet, and develops modern production techniques for these crops. Indigenous landraces are also included in breeding programs to provide a wider range of products for local food sustainability.

Table 1. The number of accessions in each crop group held by eight ARC institutes and the type of genebank in which they are conserved. Total number = 36,321 accessions.

Institute/ Crops	Seed	Field	Nursery	*in vitro*	Cryo	Crop total
Grain Crops Institute 11,575 accessions						
Summer Grains	5,020	0	0	0	0	5,020
Pulse	2,584	0	0	0	0	2,584
Oil & Protein	3,972	0	0	0	0	3,972
Small Grain Institute 3,539 accessions						
Wheat	2,499	0	0	0	0	2,499
Barley	570	0	0	0	0	570
Oats	399	0	0	0	0	399
Rye	52	0	0	0	0	52
Other	19	0	0	0	0	19
Tropical and Subtropical Crops Institute 1,698 accessions						
Tropical and Subtropical Crops	0	1,698	0	0	0	1,698
Nietvoorbij Institute 1,869 accessions						
Grapes	0	919	0	0	0	919
Yeast	0	0	0	300	650	950
Range and Forage Institute 8,183 accessions						
Grasses	2,879	152	140	0	0	3,171
Legume	4,430	35	149	0	0	4,614
Other	345	13	40	0	0	398
Infruitec Institute 1,709 accessions						
Deciduous Fruit	0	1,709	0	0	0	1,709
Tobacco and Cotton Institute 2,806 accessions						
Tobacco	1,430	0	0	0	0	1,430
Cotton	1,376	0	0	0	0	1,376
Roodeplaat Vegetable and Ornamental Plants Institute 4,941 accessions						
Ornamental	30	1,600	1,734	30	0	3394
Vegetable	700	0	0	0	0	700
Indigenous Vegetables	95	5	0	0	0	100
Potato	104	100	0	140	0	344
Sweet Potato	0	0	215	130	0	345
Cassava	0	0	32	26	0	58

The oil and protein seed research programs are directed at the breeding of improved cultivars for a variety of oil and protein seed crops to provide improved and appropriate technology to the oil industry in the country. Research covers the following crops: groundnuts, sunflower, soybeans, dry beans, lupines, cowpeas, and specialized crops such as lentils, sesame, and pigeon peas.

ARC-Small Grain Institute (ARC-SGI)

The mandated crops of ARC-SGI include wheat, barley, oats, and rye. The institute coordinates and conducts appropriate research, development, and technology transfer for the small grain industry and related sectors in South Africa. The institute's primary plant breeding function is to supply of well-adapted small grain cultivars for cereal production in South Africa. At present, cultivars developed by the GCI account for more than 60% of the annual wheat production in South Africa.

ARC-Institute for Tropical and Subtropical Crops (ARC-ITSC)

ARC-ITSC has the mandate for a wide range of crops including citrus, banana, mango, avocado, pineapple, papaya, litchi, grenadilla, macadamia, pecan and cashew nuts, as well as tea, coffee, and ginger. Lesser known exotic crops such as babaco, carambola, Surinam cherry, white sapote, coconut, feijoa, annona types, jaboticaba, pepper, and cocoa, are also being evaluated. Research activities are geared to address the problems and production limitations of both commercial and small farmers.

ARC-Nietvoorbij Institute for Viticulture and Oenology (ARC-Nietvoorbij)

The mandated crop is the grape. Research priorities are driven by the needs of table and raisin grape producers and the wine and brandy industries.

ARC-Range and Forage Institute (ARC-RFI)

The RFI focuses on the development of holistic and integrated land-use strategies through sustainable livestock and wildlife management systems. Research activities fall into two broad fields of study, namely rangeland dynamics and cultivated pastures. Rangeland research deals with the complex biological system embracing indigenous plants and plant communities and their interaction with their physical and biotic environment. Cultivated pastures research programs aim to develop appropriate cost-effective management strategies for sustainable animal production. The RFI genebank is presently the best equipped unit for short- and long-term storage of seed germplasm in the ARC. A total of 7654 accessions are kept in its genebank including the following: browse plants, tropical and temperate forage grasses, tropical and temperate forage legumes, and agroforestry crops.

ARC-Institute for Fruit Technology (ARC-INFRUITEC)

INFRUITEC's main crops include apples, apricots, peaches, pears, plums, strawberries, and almonds. The institute conducts appropriate research, development, and technology transfer for the deciduous fruit industry and related sectors in South Africa.

ARC-Tobacco and Cotton Research Institute (ARC-TCRI)

The TCRI strives to ensure the self-sufficiency of South Africa in respect to production of cotton, tobacco, and other fiber and industrial crops.

ARC-Roodeplaat Vegetable and Ornamental Plant Institute (ARC-Roodeplaat)

ARC-Roodeplaat is responsible for research and development on vegetables (including indigenous vegetable crops), potatoes, and ornamental plants.

ARC-ROODEPLAAT GERMPLASM COLLECTIONS

Genebank activities are not only undertaken to conserve germplasm of lines and material important from a breeder's point of view, but locally adapted material and material with characteristics important to all producers is also conserved. Cultivars developed by ARC-Roodeplaat, breeding lines, wild species, and certain material included in the SARRNET research program, are also conserved.

Conservation of vegetable seed

Seven hundred accessions of conventional vegetable crops are conserved as seed in a genebank. Landrace cultivars that originated through natural selection and crossing between varieties, introduced by settlers more than 300 years ago, and natural selection are included in the collection. Examples of these landrace cultivars are Cape market carrots (*Daucus carota* L.) and Caledon globe onions (*Allium cepa* L.). The collection also contains the open-pollinated cultivars listed on the South African variety list (Directorate of Plant and Quality Control, 1997). ARC-Roodeplaat maintains these cultivars and supplies breeder seed on a regular basis for the production of certified seed by the vegetable seed industry. Eighty-four accessions of *Amaranthus* species are being evaluated for production by subsistence farmers.

Conservation of potatoes, sweet potatoes, and cassava

In vitro conservation:

Potato (*Solanum tuberosum* L.), sweet potato (*Ipomoea batatas* (L.) Lam.) and cassava (*Manihot esculenta* Cranz) are conserved in an *in vitro* genebank. The conservation of potato and sweet potato germplasm at ARC-Roodeplaat was initiated in 1945, soon after the potato breeding program began and the sweet potato breeding program began in 1952. The need arose to conserve the genetic resources required by these programs, particularly with regard to sources of disease and pest resistance, as well as cultivars and lines. The material has been maintained vegetatively as neither potatoes nor sweet potatoes breed true from seed.

The potato germplasm that is conserved consists of the national cultivar collection, cultivars, breeding lines, and genetic resources of related species. The national cultivar collection is housed in a separate facility and consists of the 56 potato cultivars on the South African Variety List (Directorate of Plant and Quality Control, 1997). The national cultivar collection is subject to very strict phytosanitary, maintenance, and characterization procedures to ensure that the *in vitro* plants supplied to laboratories for the production of planting material are disease free and true to type. The remainder of the collection comprises 140 cultivars, 600–700 breeding lines, and 84 diploid accessions that are held in the *in vitro* genebank. All these accessions have been characterized and evaluated. A RAPD (random-amplified polymorphic DNA) profile is added in the case of ARC-Roodeplaat cultivars and important commercial cultivars. The six sweet potato cultivars, which account for most of the commercial production in South Africa, 210 breeding lines from ARC-Roodeplaat and the International Potato Center (CIP), and 17 old cultivars are conserved as disease-free *in vitro* plants. Some of the old cultivars in the collection originated from sweet potatoes introduced shortly after the Dutch colonized the Cape in 1652, while others were introduced from other countries over the years (Meynhardt and Joubert, 1982). This collection is well documented.

A cassava germplasm collection was initiated at ARC-Roodeplaat when it became evident that cassava had the potential to become important as both an industrial

crop as well as a food crop. During the past 15 years cassava has become known to a large portion of the population and not only to those who cultivate it on a subsistence level. The initial material included the 26 breeding lines remaining after the South African Development Trust Corporation was closed down and its breeding program abandoned. These lines originated from imported material used by the South African Development Trust Corporation to breed lines better adapted to local conditions (J. Allemann, ARC-Roodeplaat, pers. comm.). The number of accessions held at ARC-Roodeplaat has recently been increased by material received from IITA for evaluation in SARRNET trials.

Field genebanks:

The sweet potato collection is also maintained as a disease-free *in vivo* collection in an insect-proof glasshouse at ARC-Roodeplaat. The material is re-established in September each year and indexed to *Ipomoea setosa* Ker-Gawl in order to detect any virus infection. A backup collection of the 26 breeding lines from the South African Development Trust Corporation program is maintained in an insect-proof glasshouse at ARC-Roodeplaat.

Acceptance of accessions:

Germplasm of potatoes and sweet potatoes is tested for viral infection and infection by other pathogens before it can be accepted. Potatoes are tested for *Ralstonia solanacearum* (Yabuuchi et al., 1992), biovar 2 (bacterial wilt), and *Erwinia* spp. according to the methods of Kelman (1954) and Pérombelon (1971), respectively. Standard DAS-ELISA procedures are used to detect infection by potato virus M (PVM), potato virus S (PVS), potato virus X (PVX), potato virus Y (PVY), and potato leaf roll virus (PLRV). In the case of sweet potatoes, a standard isolation on potato dextrose agar is also done with regard to infection by *Fusarium oxysporum* (Schlecht ex Fries) f. spp. batatas (Wollenweber) Schnyder & Hansen and *Sclerotium rolfsii* (Sacc.). Plants are indexed on *Ipomoea setosa* Ker.-Gawl. to detect sweet potato viruses. Disease-free *in vitro* cassava material from IITA is accepted.

Storage of *in vitro* material:

After *in vitro* establishment the cultures are transferred to a storage facility. A duplicate set of cultures is held in a backup facility in a different building. *In vitro* cultures are inspected every second month with regard to vigor and the occurrence of internal contamination by opportunistic pathogens. The criteria of Lizarraga et al. (1989) are used to evaluate the cultures. Any cultures found to be unsatisfactory are removed from the storage facility and regenerated. The time between regenerations varies from 6 to 18 months, depending on the cultivar concerned.

Rejuvenation of *in vitro* material:

The cultures of potato cultivars in the national cultivar collection are rejuvenated every year, while those of other accessions are rejuvenated when vigor begins to decline. While plants are being rejuvenated, characterization data are collected and checked against information in the database. After re-establishment on *in vitro* medium, the plants are checked for specific disease organisms.

Release of material:

Disease-free potato and sweet potato cultivars are released regularly to farmers, who produce planting material under the disease-free planting material schemes of the respective industries. Potato material is supplied with a phytosanitary certificate, which states that the material has been tested for *Ralstonia solanacearum*, biovar 2, and *Erwinia* spp. as well as the potato viruses M, S, X, Y, and PLRV.

CONCLUSIONS

The ARC has significant collections of the germplasm of agricultural plants and has an important role to play with regard to the conservation of these plants in South Africa. Conservation in decentralized collections is appropriate, particularly in view of the diverse conditions and range of expertise needed for the successful propagation of these crops. These are essentially active collections with no base collections. There is a need for a long-term funding commitment, as well as base collection facilities to ensure the long-term conservation of this germplasm. ARC institutes maintain and supply seed of open-pollinated cultivars to the various industries in South Africa on a regular basis and thereby ensure the availability of these cultivars to those who need them. ARC-Roodeplaat has developed *in vitro* facilities for the maintenance and multiplication of potatoes, sweet potatoes, and cassava; these support the respective breeding and evaluation programs and supply the disease-free nuclear material on which the potato and the sweet potato industries are based. The success of this work is dependent on the support of researchers at ARC-Roodeplaat, particularly pathologists, virologists, and biotechnologists.

ACKNOWLEDGMENTS

Funds received from the Wallace Genetic Foundation and the Agricultural Research Council of South Africa to attend DNA Bank-Net III are gratefully acknowledged.

REFERENCES

Directorate of Plant and Quality Control. 1997. South African Variety List as maintained by the Registrar of Plant Improvement. January 1997.

Kelman, A. 1954. The relationship of pathogenicity in *Pseudomonas solanacearum* to colony appearance on tetrazolium medium. Phytopathology 44: 693–695.

Lizarraga, R., Huaman, Z. and Dodds, J. H. 1989. *In vitro* conservation of potato germplasm at the International Potato Center. Am. Potato J. 66: 253–269.

Meynhardt, J. T. and Joubert, T. G. 1982. The development of sweet potato varieties in South Africa. Proc. 1st Int. Symp. on Sweet Potatoes: 285–290.

Moss, H. 1994. A corporate plant genetic resources strategy for the Agricultural Research Council. Unpublished report.

Pérombelon, M. C. M. 1971. A quantal method for determining numbers of *Erwinia carotovora* var. *carotovora* and *E. carotovora* var. *atroseptica* in soils and plant material. J. Appl. Bacteriol. 34: 793–798.

Yabuuchi, E. et al. 1992. Proposal of *Burkholderia* gen. Nov. and transfer of seven species of the genus *Pseudomonas* group II to the new genus, with the type species *Burkholderia cepacia* (Palleroni and Holmes, 1981) comb. Nov. Microbio. and Immun. 36: 1251–1275.

BIODIVERSITY OF PHYTOGENETIC RESOURCES IN MADAGASCAR: INVENTORY, UTILIZATION, AND CONSERVATION FOR DURABLE DEVELOPMENT

Rakotovao Ramasiarivelo Zoeliarisoa
National Research Center for Rural Development
Department of Forestry Research
B.P. 904 Ambatobe, Antananarivo 101, Madagascar

SUMMARY

The richness of Malagasy's forest flora, which has a large number of endemic species, is reflected in the landscape and known throughout the world. It contains 12000 species with a high level of endemism; 1200 to 1600 genera (18% endemic); approximately 190 families (4% endemics). The families reported from Madagascar represent nearly half of the plants known in the world. The forests cover an area of 12 million ha. Artificial (planted) forests occupy approximately 0.04% of total area of the island. The rate of deforestation is estimated to be 200,000–300,000 ha/year. A large number of spontaneous species, often endemic, related to commercially cultivated or socially important plants, are of interest for agricultural, forestry, ornamental, and medicinal purposes. The major uses of plant genetic resources are for research (and institutions hold the national collections), NGOs, and farmers' groups. *In situ* conservation of autochthonous forest resources have been carried out in protected areas. *Ex situ* conservation is carried out on field collections, forest and research stations, and seed collections.

INTRODUCTION

Because of its insularity, Madagascar possesses an important diversity of vegetation, whose incomparable wealth is reflected in the landscape. This is the object of the newly developing ecotouristic activities. They contribute significantly to the national economy.

According to different estimates, Madagascar's flora contains 12000 species with a high level of endemism: 4000 of those have been described; 4000 are being revised; and 4000 are expected to be identified. About 600 species are introduced and acclimated. Nine-hundred fifty species are indigenous but not endemic and 86 percent are endemic. There are 1200–1600 genera with 18% endemic and around 190 families, of which 4% are endemic. The families reported in Madagascar represent nearly half of the plant families known in the world.

The area of Madagascar is around 600,000 km^2. The natural forests covered an area of about 53.1 million ha in 1927. Forests are being more and more damaged (17 million ha were located in 1969, but only 12 million ha were found in 1984; i.e., 20% decrease in forested area). The forests have economic benefits and considerable scientific value, as well as provide protection for the environment, refuge for wildlife, wood, and medicines for man's use.

The actual rate of deforestation is estimated to be 200,000–300,000 ha/year. If destruction is continued at the current rate, only the forest on abrupt slopes will survive during the next 35 years. At present, the artificial (planted) forests occupy an

approximate area of 260,000 ha (0.04 % of total area of the island). The largest portion is composed of pines and eucalyptus in the highland and cashew trees in the northwest; these are of economical importance. The cultivated area represents only 3.6% of the total area, but the yield is low and insufficient while the population is increasing (from 2.9%–3.1% per year). This increase in population exerts a pressure on the land. This unbalance should be solved by a durable and rational management policy of existing plant genetic resources. The durable management should focus on re-establishing uncultivated lands, taking action concerning sustainable use of soils and ensuring resource preservation.

This paper reviews the potential diversity of plant genetic resources in Madagascar and the main reasons for its degradation. The paper also attempts to invite any interested parties to do everything possible to provide the strategies to preserve and improve the food value of this precious genetic patrimony to help assure food security.

POTENTIAL DIVERSITY AND UTILIZATION OF PLANT GENETIC RESOURCES

Local species

Spontaneous species

Spontaneous species do not have a direct economic impact but have a scientific value. Madagascar has many spontaneous varieties, which are mostly endemic and related to commercially cultivated or socially important plants. The following is a list of some of the most important crops:

- rice is the staple food for the Malagasy people. The whole set of Malagasy natural varieties is held in a research collection. However, two wild species of rice, *Oryza longistaminata* and *O. punctata*, resistant to RYMV (rice yellow mottle virus) were not represented in collection, so they are threatened;
- many leguminous species (wild *Vigna*);
- greens that represent a daily meal of Malagasy people;
- edible tuber crops widely grown by peasant farmers and used as food during dry seasons;
- many fruit crops provide more calories and vitamins for the rural populations or are used to feed animals. 150 species with 92% woody, 80% endemic, 5% of the indigenous taxa have been identified. Among the 30 species that are thought to be important for use as multiple purpose trees, or represent food security for local inhabitants during times of crop failure, are: tapia (*Uapaca bojeri,* Euphorbiaceae) also used as firewood; *Phyllarthron madagascariensis (*Bignoniaceae); *Andansonia* spp. (Baobab, Bombacaceae); *Syzygium* sp. (Myrtaceae) edible by animals or by humans; *Ficus* sp. (Moraceae); *Raphia ruffia* (Palmaceae); *Strychnos madagascariensis* (Loganiaceae); *Sorindea madagascariensis* (Anacardiaceae); *Terminalia* sp. (Combretaceae); cactus, *Musa perrieri* (wild banana-tree, Musacea); *Ravenala madagascariensis* (Musaceae); wild lemon (Rutaceae)
- spice crops include wild pepper, wild hot pepper (classified as aromatic plants and widely used as culinary ingredients);
- forages (grass or small trees) of interest to the grazing system;
- fiber crops: *Raphia ruffia*, *Urena loubata* (Malvaceae) exploited for fiber use;
- cash crops: wild pepper, wild coffee including *Mascarocoffea* with no caffeine composed of 50 botanical species; wild vanilla.

The degradation of forest is a constant threat to these genetic materials.

Land varieties and old cultivars

The appropriate way to ensure food self-sufficiency is to use techniques relying on improved varieties for technological innovation. The cultivation of newly created varieties may lead to a loss of natural genetic resources.

Fortunately, land varieties and old cultivars have been conserved due to the conservation skill of traditional farmers. The Malagasy farmer could create his own variety on the basis of visual criteria. Such are the cases of many varieties of red rice, aromatic rice (jasmine rice), wild ginger, *Vigna*, yam, and sweet and white potatoes, etc.

Forest species

The forest flora contains a high number of endemics. Ninety percent of the endemic species are found in the humid forests of the east coast.

- Among the spontaneous or sub-spontaneous species, 60,000 ha per year of some 20 woody timber species are exploited for export (of ebony, rosewood) or for local construction (*Commiphora*, *Canarium*, *Neobeguea, Eugenia*, *Ocotea*).
- Approximately 31 uncommon forestry species will be lost if action for conservation is not taken. Some of these species are: *Andansonia grandidieri* (baobab), aloe (Liliaceae), *Euphorbia*, *Hernandia*, *Khaya madagascariensis* (Meliaceae).
- Ornamental plants: orchids and ferns.
- Many medicinal plants with potential value for natural product development are known: 2300 species for traditional pharmacopoeia have interested 60 percent of the population. Examples are: members of Apocynaceae (*Catharanthus* used for stomachache); Droseraceae (*Drosera madagascariensis* as anti-cough); Apiaceae (*Centella asiatica* against ulcer); Rosaceae (*Pygeum africanum,* used to treat prostatitis, is the most important medicinal species exported from Madagascar—more than 600 tons of bark are exported per year).

Introduced species

Since the colonial era, the natural flora has been enriched by voluntary or accidental introduction. Species introduction for economical or social purposes included rice, maize, potato, cassava, corn, peanut, coffee, medicinal, and aromatic plants.

Edible fruit crops were introduced as early as the tenth century and are well integrated in natural vegetation. They are: bananas, coconuts, lemons with giant fruit, mangos, pomegranates, and vines.

Most fruit crop species were introduced between the 19th and 20th centuries, such as apples, peaches, apricots, plums, litchis, avocados, different pineapple varieties, guavas, and papaws. Most of these are cultivated on a large scale. Some regenerate naturally and have been the object of gathering, as source of income for local people.

A number of forestry species or families were introduced by the National Forestry Research Center since 1970 within international provenance trials coordinated by the Commonwealth Forestry Institute in Oxford, or in seed/clonal orchards for the genetic tree improvement program. The main species are: *Pinus kesiya*, *P. elliottii*, *P. caribea*, *P. patula*, acacia, and eucalyptus.

THE CAUSES OF DECREASES IN BIODIVERSITY

The main threats to forest resources result from deforestation and degradation of the tree cover. Destruction of forests has been caused by farming practices on "tavy,"

i.e., on a patch of dentured land to get more and more new, rich lands. Wildfires are also the greatest obstacle in natural regeneration of vegetation. The increasing degradation of wood resources creates an irreversible deterioration of soils. Lack of forest cover is heightened by cyclones or floods. Natural regeneration does not occur because of the exaggerated and uncontrolled exploitation of natural resources. Ecosystem degradation due to deforestation, diseases, and pests may have caused the loss of a great part of the biodiversity. Some traditional varieties had been forsaken for the benefit of a few improved varieties. It appears that this is one cause for the reduction of the biodiversity.

Some of plant genetic resources disappeared because they have been neglected or haven't had a direct economic impact. On the other hand, some species have been excessively exploited by uncontrolled collecting, exporting beyond measure, or the shrinking of the forest. A large portion of the forests have been destroyed and more forests are threatened.

CONSERVATION OF PLANT RESOURCES

Madagascar, a developing country, with up to a 3% rate of increase per year in population (12 million inhabitants) is trying to solve its food and agricultural problems. As mentioned, biodiversity is exposed to many threats. Madagascar is pressured to take appropriate actions for the preservation of the available resources to act as security for food sources. Agriculture needs to find a way to maintain the increasing number of people without degrading the environment. By destroying the forest, millions of plant species dependent on forest have been lost. Better management of the natural environment is thus necessary for the conservation of biodiversity because this biodiversity is indispensable to ensure alimentary sufficiency and livelihood.

Until now, a veritable national program of plant genetic resources did not exist; there are mostly different actions, assumed by various organizations. There are laws and controls on using natural resources, but they are not well enforced. Nevertheless, two forms of conservation have currently been considered to guarantee long-term preservation of plant resources.

In situ conservation (conservation in natural stands)

In the past, it was traditional for Malagasy ancestors to have respect for nature. Some forests or woodhills were sacred or taboo. Due to the social and economical degradation, destruction has prevailed over preservation. So, strategies of serious conservation, including good management, need to be developed. Old cultivars or land varieties are preserved on the peasant's field. Farmers are developing, every year, a multiplicity of ecotypes. *In situ* conservation of forest resources is integrated into planning an environmental program and has been carried out in protected areas (33 national reserves, 22 botanical gardens, 3 national parks) that occupy about 1,034,782 ha. Several non-governmental organizations are working on conservation and durable management of natural ecosystems (ONE, ANGAP, WWF, ANAE, CI), but there is not any official coordination.

Ex situ conservation (conservation outside the natural range)

Madagascar does not have a veritable national genebank. Valuable plant resources and germplasm of introduced materials are generally maintained in research stations where field collections, large plantations, or stand conservatories (Table 1)

Table 1. Germplasm collections of commonly cultivated plants in Madagascar.

Species	Holder organization	Accessions	Sources of germplasm
Cereals			
Rice	FOFIFA	4127	land varieties + introductions
Maize	FOFIFA	169	introductions +
	FIFAMANOR	2570	local selection from
Triticale	FIFAMANOR	603	hybrid progenies
Oats	FOFIFA	15	introductions
Orge	FOFIFA	34	introductions
Maize	FOFIFA	371	introductions + local ecotypes
Tuber crops			
Cassava	FOFIFA	330	introductions + local
	FIFAMANOR	67	ecotypes
Potato	FIFAMANOR	181	introductions + some local
Sweet potato	FIFAMANOR	72	ecotypes
Legumes			
Peanut	FOFIFA	349	
Beans	FOFIFA	321	land varieties +
Vigna	FOFIFA	135	introductions
Vouandzou	FOFIFA	28	
Soya	FOFIFA	272	
Industrial crops			
Cotton	FOFIFA	160	introductions
Sugarcane	FOFIFA	338	land varieties +
	SIRAMA	77	introductions
Cash crops			
Coffee			
canephora	FOFIFA	779	land varieties
arabusta		28	hybrid
arabica		329	introductions + local ecotype
mascarocoffea		146	endemic
Pepper	FOFIFA	195	
Vanilla	FOFIFA	3000	hybrid progenies + 17 local ecotypes
Fruit crops			
Mango		46	
Banana		12	
Granadilla		5	introductions
Guava		8	
Papaw	FOFIFA	5	
Agrumes		25	
Peach			
Plum	SMV	?	introductions
Khaki			
Apple			
Forages	FOFIFA	20	3 spontaneous varieties
	FIFAMANOR	207	Land varieties + introductions

where the different varieties were developed. Some direct users have their own collections. The main collections (Table 1) of cultivated crops are held by FOFIFA in 13 locals stations for 6 cereal plants, 4 tuber crops, 5 leguminous, and 11 fruit crops. Some medicinal plant collections are found in park and botanical gardens for research needs.

Introduced forest species are maintained in arboreta or forest stations. A seed bank for forest species is held by SNGF (National Seed Center), which is working on the production and popularization of introduced species.

Although the tissue culture laboratory had been set up at DRFP/FOFIFA, plant biotechnology activities are still in early development. *In vitro* germplasm conservation of a few food crops are carried out by some organizations, including FIFAMANOR, and the Plant Protection Service.

CONCLUSIONS

The ways in which Madagascar uses its wealth of flora are very diversified. Many activities relating to plant genetic resources correspond with national planning development, in order to develop, strengthen and create an inter-ministry coordination for durable utilization and preservation.

Therefore, it seems that efforts for conservation projects are relatively few in regards to the requirements of food needs. The general policy of alimentary security has the following goals:

- a better quality of life;
- improving agricultural yield;
- ensuring domestication occurs in many areas for the most utilized species to provide different seed sources (germplasm), which would reduce the pressure on the national resource base;
- valorizing available resources, while undertaking their adequate management and rational utilization;
- reinforcing the measures of conservation and rational utilization of plant genetic resources, namely of resources threatened to extinction;
- instituting appropriate environmental preservation.

These actions not only imply the involvement of government or non-government organisms but also of the involvement of the entire population of Madagascar.

GENERAL REFERENCES FOR FURTHER READING

Andriamampianina, J. 1981. Les reserves naturelles et la protection de la nature à Madagascar. Edition Philippe Oberlé.

Andrianarivelo, R. 1989. Population, ressources naturelles, environnement et développement-BIT/FNUAP, Projet MAG/87/P02.

Capuron, R. 1957. Essai d'introduction à l'étude de la flore forestière de Madagascar. Centre Technique Forestier Tropical.

Chauvet, B. 1987. Inventaire des espèces forestières introduites à Madagascar. Université de Madagascar. ENSA.

CTFT. Les plantations de Pins à Madagascar et au Cameroun.

Humbert, H. et al. 1936. Flore de Madagascar et des Comores. Muséum d'Histoire Naturelle, Paris, France.

Koechlin, J. 1972. Flora and vegetation of Madagascar. Biogeography and Ecology in Madagascar. Monographiae Biologicae 21. The Hague, The Netherlands.

Perrier de la bathie, H. 1933. Les plantes introduites à Madagascar. Henri Basuyau & Co., Toulouse, France.

Rabesa, Z. A. 1990. Notes on Malagasy plants utilized in the traditional Pharmacopoeia. *In:* First International Congress of Ethnopharmacology, held in Strasbourg, France.

Rakotomalala, J. J. 1995. Rapport de Madagascar sur les Ressources Phytogénétiques Antananarivo, Madagascar.

Rakotovao, Z. Rakotondraoelina and H. Rasamimanana, A. 1996. Bilan de 20 années de Recherche en Génétique Forestière. Centre National de la Recherche Appliquée au Developpement Rural/FOFIFA. N° 721/DRFP.

Razanaka, S. J. 1989. Délimitation des régions de Provenances pour les semences forestières à Madagascar. Mémoires de DEA. Université d'Antananarivo.

Styger, E., Rakotoarimanana, J. E. M. 1990. A la découverte des espèces ligneuses fruitières indigènes de Madagascar. MADR/PASN/SNGF.

Sutter, E. and Rakotonoely, J. 1990. Introductions d'espèces exotiques à Madagascar. Projet Inventaire des ressources ligneuses. MRSTD/FOFIFA/DRFP.

UICN. 1987. Priorité en matière de conservation des espèces à Madagascar.

ACRONYMS

ANGAP	National Association for Protected Areas Management
ANAE	National Association for Environmental Actions
CI	International Conservation
DRFP	Department of Forestry and Piscicultural Research
FIFAMANOR	Madagascar-Norway Bilateral Co-Operation
FOFIFA	National Research Center for Rural Development
ONE	Environment National Office
SMV	Seed Multiplication Service for Agricultural Crops
SNGF	National Silo of Seed Forests
UICN	International Union for Nature Conservation

Appendix I. List of uncommon forest plants threatened with genetic erosion
W = Woody; H = Herbaceous Source: UICN

Scientific name	Form	Family
Adansonia grandidieri	*W*	*Bombacaceae*
Aloe helenæ	*W*	*Lilaceae*
A. suzannæ	*W*	*Lilaceae*
Alluaudiopsis	*W*	*Didieraceae*
Angrœcum leonis	*H*	*Orchidaceae*
Baudouinia rouxevillei	*W*	*Leguminosae*
Decariopsis madagascariensis	*W*	*Arecaceae*
Brachylœna microphylla	*W*	*Asteraceae*
Cryptocarya louvelii	*W*	*Lauraceae*
Diospyros microrhombis	*W*	*Ebenaceae*
D. perrieri	*W*	*Ebenaceae*
Eulophiella	*H*	*Orchidaceae*
Euphorbia pachypoides	*W*	*Euphorbiaceae*
E. pirahazo	*W*	*Euphorbiaceae*
E. quartziticola	*H*	*Euphorbiaceae*
Grammangis	*W*	*Orchidaceae*
Hernandia voyronii	*W*	*Hernandiaceae*
Humbertia madagascariensis	*W*	*Humbertiaceae*
Isaloa lepida	*W*	*Scrophulariaceae*
Khaya madagascariensis	*W*	*Meliaceae*
Lemuropisum edule	*W*	*Leguminosae*
Pachypodium decaryi	*W*	*Apocynaceae*
Perriera madagascariensis	*W*	*Simarubaceae*
Phyllarthron megapterum	*W*	*Bignoniaceae*
Ravenea	*W*	*Arecaceae*
Santalina madagascariensis	*W*	*Rubiaceae*
Takhtajania perrieri	*W*	*Winteraceae*
Vonitra utilis	*W*	*Arecaceae*
V. crinata	*W*	*Arecaceae*
V. thouarsiana	*W*	*Arecaceae*
Zygosicyos	*H*	*Cucurbitaceae*

COLLECTION, CONSERVATION, AND UTILIZATION OF MEDICINAL PLANTS

Zac. O. Gbile
Ogun State University
G.P.O. 12747
Ago-Iwoye, Nigeria

SUMMARY

The study of medicinal plants has gained international attention. The World Health Organization encourages every nation to strive to provide health care for all its citizens. Scientists in Nigeria collaborate with traditional healers in the collection of plant material for their research, and confirmation of identification is often carried out at the Forest Herbarium in Ibadan (FHI). Conservation strategies are usually designed by the Federal Department of Forestry, Federal Environmental Protection Agency, the State Forestry, and the Forestry Research Institute of Nigeria. There are at present 18 game reserves and 1 national park in the country. The resolutions of the Advisory Committee set up by the Natural Resources Conservation Council on the conservation of medicinal plants are outlined. Some of the various plants utilized in the country are discussed. The activities of National Institute for Pharmaceutical Research and Development are briefly discussed. Conclusively, the nation as a whole should be conservation conscious.

INTRODUCTION

At the inception of the Forestry Research Institute of Nigeria in Ibadan, the research interest was centered around trees that are sources of timber. There was not much emphasis on the understory trees, which are commonly utilized for medicinal purposes. However, having observed this, I included in my proposal, as from 1970s, the studies of herbs, suffrutex, etc., usually employed in medical care.

Much global attention is now focused on finding ways of exploiting our natural and indigenous resources with their ultimate utilization as sources of pharmaceutical raw material. There is no doubt that medicinal plants growing in Nigeria will continue to be an important source for raw materials and new drugs for pharmaceutical manufacturing, provided adequate funds, infrastructural, man power, and facilities are available for the exploitation of these resources.

In most gardens in Nigeria, species of frequent occurrence include: *Euphorbia hirta* (diarrhea and typhoid), *Cassia alata* (purgative), *Talinum triangulare* (purgative, anti-hypertensive, and food), *Ageratum conyzoides* (juice used for fresh cuts), *Ocimum gratissimum,* (which contains an antiseptic, thymol, used for diarrhea). Some of these are considered weeds and are often cleared from time to time. Since they are not conserved, they disappear during the dry season and are not available for medical care.

Concerned circles readily acknowledge the important role played by forestry in conservation and in the economy of the nation. In addition to its measurable contributions toward the provisions of consumer and producer goods, the ubiquitous externalties related to forestry are also admitted to be quite significant. The onus of

preserving our wild flora to make the local sourcing of pharmaceutical products a reality rests not only on the foresters but on us all.

At the World Health Assembly in 1977, it was resolved that every nation should strive to provide health care for all its citizens by the year 2000 (Kio and Gbile, 1987). This decision presupposes that we should do all that is possible to ensure that most, if not all the pharmaceutical products needed for drug production are manufactured locally before the target date, which is barely 3 years from now. There can be no meaningful health-care delivery without provision for the use of drugs.

Demand for drugs is enormous, and our human resources are quite impressive. Although our financial resources may be comparatively lean, Nigeria is still regarded as a wealthy nation. From research reports on locally available raw materials, there is complete evidence that local raw materials may in the future adequately replace those currently being imported into the country. However, our success in this respect as a nation depends on our attitude, seriousness of purpose, and determination to succeed.

COLLECTIONS OF MEDICINAL PLANTS

Early collections of medicinal plants were already discussed (Gbile, 1994). During the past years, the staff of the Forestry Research Institute of Nigeria collected a good representation of plants that made up the vegetation cover of the country. In recent years, activities in this respect have slowed down as a result of political and economic instability.

Until the early 1970s, the institute also collected and shipped medicinal plants to developed countries where they are screened, analyzed, and used in drug preparations, only to be sent back to developing countries as high-priced medicines. It is gratifying to note that our indigenous scientists have taken considerable interest in research into our traditional medicine. Most universities that are involved in the investigation of medicinal plants collaborate with traditional healers in the collection of the plants they investigate; confirmation of identification is usually carried out at the Forestry Research Herbarium in Ibadan (FHI) where over 100,000 specimens are housed.

There is a need for Nigeria to be self-sufficient in the production of pharmaceutical and drug products. One of the ways to achieve this objective is by the collection and exploitation of our local raw materials in manufacturing industry.

CONSERVATION

In Nigeria, the total land area is 923,768 ha. Of this amount, forests account for only 9.61%; grasslands, 48.53%; fresh water and wetlands 20.33%; mangrove 1.05%; and farmlands 20.33%.

According to the World Conservation Monitoring Center (1988), only 1.7% of Nigeria's land area is included within protected areas, with a further 1.1% proposal for protection. Even those "protected areas" are being degraded by poaching, illegal logging, farming, grazing, and road-building. There has been rapid degradation of Nigeria's forest reserves because the system and its controlling legislation are ineffective and do not control the exploitation or management of these valuable resources.

The Federal Department of Forestry and the Natural Resources Conservation Council (now Federal Environmental Protection Agency), the State Forestry and Forestry Research Institute of Nigeria are the major governmental conservation organizations in Nigeria. There are at present 18 game reserves and 1 national park in the country (IUCN, 1987).

Conservation measures taken by the Nigerian Government in the past had their problems. However, in 1985, a giant step was further taken by the formulation of a National Conservation Strategy, which gave birth to the National Resources Conservation Council (NARESCON) by Decree No. 5 of 1989. The "Function of Council" made provision for NARESCON "to coordinate matters concerning the conservation of natural resources in Nigeria."

Furthermore, the National Conservation Strategy, in its third recommendation, called for a Conservation Action Plan to arrest the rapid degradation and depletion of our national resources and enhance coordinated development of Nigeria's renewable natural resources. In 1992 NARESCON came out with a National Resources Conservation Action Plan (Advisory Committee on Conservation, 1992), which includes recommendations for conservation of medicinal plants. The author of this paper was a member of the team of experts involved in the plan. The recommendations include the following (Advisory Committee, 1992):

1. A team of experts including pharmacognoists, botanists, medical doctors, chemists, and traditional healers should be set up to carry out ethnobotanical surveys of different vegetation zones of Nigeria, realizing the vital roles plants play in the health of mankind. Herbalists and traditional healers often die with their rich knowledge undocumented. Such irrecoverable losses should be stopped.

2. Provision should be made for the propagation of medicinal plants (*ex situ* conservation) both at the national and state level.

3. The State Forestry Division should focus its attention on forest reserves, especially in the lowland rain forest. They are currently managed for timber extraction and are subject to abuse such as illegal logging and boundary encroachment in clearing lands for agriculture. The biological, genetic, and ecological values of most lowland rain forest reserves far outweigh any timber value. They must be protected as part of the national heritage and as a genetic resource for the future.

4. The Federal Department of Forestry should encourage an inventory of the extent and value of secondary forest products as part of the National Forest Resources Survey. Local people should benefit extensively from these resources, and their value must be included in economic analysis and planning.

5. There is an urgent need for the establishment of a National Botanic Garden associated with a National Herbarium, where different aspects of research into the maintenance of biodiversity of our plant resources, *in situ* and *ex situ* conservation, will be carried out. A committee of botanists should be set up to look into the location, manpower, and financial requirements of these two establishments.

6. Representative vegetation zones in each local government should be identified and protected.

7. Legal forces should be given to the protection of strict natural reserves.

8. Funds should be provided for the exploitation of swamp forestry research. Efforts should be made to set up machinery for the utilization of mangrove species.

9. In desert-encroached area of the country, an effective enlightenment campaign should be initiated and sustained by use of various news media, educational programs, and extension services, and by encouraging and enlisting the support of relevant voluntary organizations and societies.

10. Because exploitation of forests for fuelwood constitutes a drain on the wood resources, it would be wise if efforts are made to inform the people on the use of non-local materials for cooking.

11. Fodder plants should be planted along traditional grazing routes and at the dry season concentration sites to reduce livestock damage on the existing browse trees and medicinal herbs.

As often indicated, the exploitation of medicinal plants is total. Plants are uprooted to provide the desired plant part: for example, roots, or in some cases the debarking of trees, a treatment that is physiologically referred to as girdling and that results in the death of the tree or other plants. Apart from this, flowers or fruits may be the desired plant part, in which case no fruit are allowed to develop or no seeds are available for regeneration in the wild. These practices coupled with the naturally low level of fruit production, insect attack, or specifically rodent attack on fruits and seeds result in lack of seed for regeneration. It is absolutely necessary that efforts be taken to rescue our plant resources from extinction.

The universities are not without their roles in conservation. The universities of Ibadan and Obafemi Awolowo maintain botanical gardens and grow medicinal plants for research. Ogun State University in Ago-Iwoye is a newer university with a good conservation program. The location is in a high forest, which is very rich in flora. A portion of the land is mapped out for a botanical garden. The university has also embarked on the establishment of a teaching herbarium. Emphasis is on the teaching of ethnobotany in the botany unit of the university, which is also involved in research into anti-hypertensive and anti-diabetic plants.

UTILIZATION

As a result of the dwindling economy of the country, most people on meager income cannot afford to purchase orthodox drugs and as a result they go to herb markets and traditional healers to purchase remedies for their medical needs. This practice has increased the exploitation of the medicinal plant resources in the country.

At the National Institute for Pharmaceutical Research and Development in Abuja, attempts are being made to cultivate some of the plants needed for the production of drugs. This is not without its problems as most plants in the southern states of the country cannot thrive successfully in the harsh dry weather of the north. I worked with the institute as UNDP Consultant for the establishment of an herbarium and maintenance of a medicinal plant garden. One of the suggestions given to the institute was to make provision for an adequate irrigation system to enable it to get meaningful results in their *ex situ* conservation program. They have, however, taken bold steps in the establishment of *in situ* and *ex situ* conservation. Most of their raw materials, however, are still obtained from the wild.

At present some of the species raised in their *ex situ* conservation plots include: *Anogeissus leiocarpa* (leaves for anti-malaria and insomnia, roots for hemorrhoid); *Azadirachta indica* (leaves for anti-malaria); *Bridelia ferruginea* (root decoction diuretic, stem barks used as mouthwash); *Cassia alata* (pulped fresh leaves applied to skin diseases: herpes, blotch, eczema, mycosis, ringworm); *Daniella oliveri* (infusion of powdered bark and buds used for headaches, migraines, feverish pains); *Eucalyptus citriodora* (at present a major source of volatile oil for the institute); *Jatropha curcas* (roots or seeds used for constipation, leaves for abdominal colic/pains); *Khaya senegalensis* (powdered stem bark as anti-malaria, anti-hypertensive, and anti-diabetic); *Morinda lucida* (anti-malaria, anti-hypertensive); *Parkia biglobosa* (decoction of stem bark as anti-hypertensive); *Prosopis africana* (root decoction for toothache, boiled seeds for sore throat); *Psidium guajava* (leaves as anti-malaria); *Sarcocephalus latifolious*

(root bark as anti-malaria); *Vernonia armygdalina* (leaves as anti-malaria); and *Vitex doniana* (decoction of stem bark for asthma).

Other areas that are being investigated in the country include the following.

Essential oils

Essential oils are used in medicine and dentistry because of their bactericidal or anti-parasitic properties. They are also used as insecticides, in making of perfumes, soap and toiletries. They supply flavoring agents for food and alcoholic and soft drinks.

Oliver (1960) gave a comprehensive list of useful plants containing essential oils in the country, including the following:

(a) Citrus sp. (Rutacae)

The citrus fruits and leaves contain a fairly large amount of terpenes, alcohols, and acetates (Kefford and Chandler, 1970; Attaway et al., 1966). Citrol and thymol, which are major components of citrus leaf and peel essential oils, show strong antiseptic properties. Leaf essential oils can be analyzed for these chemicals and used directly in combating infection of the bronchial and urinary tracts and in preventing sepsis of burns and wounds. Thymol is known to be about 20 times as efficacious as phenol and can be incorporated in mouthwashes and even in toothpastes in which their antiseptic properties and rubefacient action on the gum are most beneficial.

(b) Eucalyptus species (Myrtaceae)

The essential oil of the leaves of *Eucalyptus cameldulensis, E. tereticornis,* and *E. citriodora* has been investigated (Akinloye and Adegbehin, 1984). Cineole, citronellol, and citronellal were identified as major constituents of the three species. The relative abundance of these compounds in each species was also established. Apart from a potential use of the oil in the *Eucalyptus* oil mill industry and the perfume industry, the lemon-scented oil may be incorporated in pharmaceuticals. For instance, *Eucalyptus* syrup anti-cough solutions and suppositories have very strong anti-bacterial action. The volatile oils may also be used as an expectorant or decongestant (Oliver, 1960).

(c) *Zingiber officinale* (Zingiberaceae)

Zingiber officinale is highly esteemed for its pleasant aromatic odor and pungent taste. Its rhizome is used locally as an ingredient for pepper soup and a refreshing drink. The rhizome decoction is considered antibacterial, anticatarrhal, anti-convulsant, and anti-rheumatic in ethnomedicine. The pungent principles of ginger include gingerols, shogaols, zingerome, and dehydrogingerol (Connell and Lachlan, 1972; Kami et al., 1972; Murata et al., 1972).

(d) *Elaeis guinensis* (Graminieae)

Crude palm kernel oil has been used for years as an emollient and in the preparation of local cosmetic products. The oil could be a good substitute for a number of fixed oils and suppository bases presently being imported into the country. Most companies complain about the odor. The use of oil in local formulation can be assured after a thorough investigation into the physio-chemical properties of the oil has been carried out, and the pharmacological and toxicological screening completed.

Starch

The starch used by most pharmaceutical companies in the country is derived from *Manihot esculent,* (Cassava), *Colocasia esculenta* (Coco yam), *Zea mays* (Maize), *Dioscorea* species, and *Solanum tuberosum* (Irish potato). They are used as disintegrant, filler in tables, and in capsule formulations. Starches suitable for table manufacture have been found in large quantities in cassava and cocoyam.

(a) *Manihot esculenta*

Research has shown that cassava starch is a better distintegrant than other starches now in common use for tablet formulation. In addition it possesses significant lubricant property. None of the other starches now imported has this added property. A cassava industry has been set up in the eastern part of the country. Greater refinement is, however, required in the purification of cassava starch to make it suitable for pharmaceutical uses.

(b) *Zea mays* (Gramineae)

Glucose (dextrose) is used in sterile solutions for injection to provide a readily metabolized nutrient. It is also used as supplement to milk for infant feeding in preference to lactose. This is a very important pharmaceutical material, which can be processed from corn (maize) (Essien, 1985).

Flavors and sweeteners

In the formulation of drugs, pharmaceutical additives like flavors, sweeteners, and coloring or excipients for tablets are also needed. A recent review (Obiorah, 1982) shows that these pharmaceutical additives, which drain considerable foreign exchange from Nigeria, can, and should be made from local materials and developed through intensive research at National Institute for Pharmaceutical Research. *Saccharum officinarum* (sugarcane) is now being processed for sucrose and alcohol in some parts of the country.

(a) *Allium sativum* (Alliaceae)

Allium sativum is much grown as a condiment and medicine. By steam distillation, fresh bulbs can yield an essential oil called the "oil of garlic." A valuable flavoring in meat preparation, soups, sauces, and canned goods, it contains allyl-propyl-disulphide and two other sulphide compounds (Oliver, 1960).

(b) *Carissa edulis* (Apocynaceae)

The edible fruit is red, turning to black, with a sweet cherry flavor. The roots yield an essential oil. Locally, pieces of root are used to flavor food and drink or as a tonic.

(c) *Thaumatococcus danielli* (Maranthaceae)

Thaumatococcus danielli is commonly grown under shade in rain forests for its leaves, which are used to wrap corn pap and for the preservation of cola nuts. The aril was investigated and the extract was found to be 4000–5000 times sweeter than sucrose and has been considered the sweetest natural substance in the world (Adesina, 1976). The sweet protein extract is known under the trade name "TALIN." Talin can be substituted for sugar in some pharmaceutical preparations, food, and drinks, particularly for diabetics. *T. danielli* propagates very easily by rhizome.

(d) *Dioscoreophyllum cumminsii* (Menispermaceae)

The fruit of *D. cumminsii* has also been investigated (Adesina, 1976); the protein extract has been found to be 2000 times sweeter than sucrose. Other modes of propagation should be studied, as efforts to germinate it by seeds have so far not been very successful.

(e) *Xylopia aethiopica* (Annonaceae)

Due to its spicy nature, its use in herbal medicines may be due to its preservative property (Boakye-Yiadom and Fiagbe, 1977). The production of essential oils from it has been reported (Ekung and Ogan, 1968). Alkaloids and tannins have also been reported from the leaves (Odebiyi and Sofowora, 1978). In traditional medicine,

powdered dried fruit mixed with red oil is used for the treatment of cough. It is also a part of the recipe for anti-convulsant and amenorrhoea preparations (Kio et al., 1986).

Gums and waxes

Gums are used in pharmaceutical industry as suspending and emulsifying agents. *Zanthoxylum* gum has been investigated for its emulsifying properties and was compared with *Acacia* and tragacanth, the two traditional emulsifying agents. A lot has been done with the root of *Zanthoxylum zanthoxyloides*. The water extract possesses anti-sickling effects (Sofowara and Isaac, 1971). Powdered root extract is used in traditional medicine for the treatment of toothache. Stem bark, fruits of *Piper guineense* and fruit of *Xylopia aethiopica,* powdered and mixed with pap and taken every morning, provides a cure for general weakness (Kio et al., 1986). The liquid wax of *Simondsia chinensis* (jojoba) provides an excellent lubricant, in addition to supplying raw material for a variety of other industrial, cosmetic, and medicinal processes and products.

Anti-malaria

In the traditional system of medicine, several species are commonly included in a single prescription for malaria. It is generally believed that in such poly-prescription, the individual effect of the plant species that is specific for the disease is rendered more effective with less harmful side effects than when it is used alone.

(a) *Azadirachta indica* (Meliaceae)

Most advocates of *A. indica* use it alone in the treatment of malaria. The leaves are usually boiled in water and the extract taken in single or multiple doses. The efficacy of the extract against malaria infection is claimed to be superior to the usual shizontocidal drugs such as chloroquine and amodiaquine (Oliver, 1960). It is, however, suggested that the effective dose and toxicity of *A. indica* as an anti-malarial agent should be determined to minimize the attendant risk of the medication (Iwu et al., 1986).

(b) *Picralima nitida* (Apocynaceae)

Picralima nitida is a tree of the high forest used in traditional medicine for the treatment of malaria fever, colic symptoms, dysmenorrhoea, and hypertension (Irvine, 1961). Several alkaloids have so far been isolated from the seeds, but the major alkaloidal principle (0.56%), akuammine, has chemical characteristics that are apparently similar to morphine (Gbewonyo and Addy, 1983).

(c) *Mangifera indica* (Anacardiaceae)

The leaves, stem, and root bark of *M. indica* are usually added to other plant parts as an anti-malarial agent. Such boiled decoctions are usually taken to relieve fevers, aches, and pains. Chemical evidence for its efficacy is lacking.

(d) *Carica papaya* (Caricaceae)

Root bark of *Khaya* species, leaves of *Cymbopogon citratus,* and *Carica papaya* are common recipes for malaria treatment. The chemistry and biological values of the drugs have been reviewed (Gbile and Adesina, 1987; Taylor, 1986). In traditional medicine, unripe but mature fruits of *C. papaya* have been found to be very effective for the treatment of diabetes in folklore medicine. This is yet to be supported by chemical evidence. Pappain, a hydrolizing enzyme, has been obtained from the latex of the fully developed unripe fruit, which has a number of uses in the pharmaceutical, cosmetic, and food industries. It is also used in preparations to control edema and inflammation associated with surgical or accidental trauma, infection, and allergies.

Anti-gonococcal

Gonorrhea is one of the most common communicable diseases in both developed and developing countries. A significant observation made was the highest antigonococcal activity of *Acacia nilotica, Phyllanthus reticulatus,* and *Sida serratifolia.* It is interesting to note that an extract of *A. nilotica,* which is used by traditional doctors as curative for tuberculosis, pneumonia, and small pox, is also active against *S. aureus* and *E. coli.* The extract also is active against *N. gonorrhoeae,* which is resistant to 5 units of penicillin (Haensel and Zander, 1961).

Anti-asthmatic

It has been reported that extracts of *Desmodium adscendens* have shown anti-anaphylactic action on isolated preparation from sensitized guinea pig (Haensel and Pelter, 1969). This work gives support to the potential use of the plant material as a good anti-asthmatic preparation for use prophylactically.

Anti-diabetic

Apart from mature unripe fruit of *Carica papaya* used in traditional medicine for the treatment of diabetics, *Tecoma stans,* which occurs in the tropics as a popular garden ornamental shrub, is also anti-diabetic. Glucolisine and diabetoline, which are yet to be recognized effective by the medical profession, were reported from it.

Anti-hypertensive

(a) *Rauwolfia* species (Apocynaceae)

The alkaloid reserpine, which is used in the treatment of hypertension, is extracted from *R. vomitoria* in Nigeria and *R. serpentina* in India. *R. vomitoria* can easily be cultivated for the extraction of reserpine and other pharmaceutically important alkaloids.

(b) *Lippia multiflora* (Verbenaceae)

L. multiflora is a aromatic herb that grows in derived savanna. Collections have been made around Awo in the Ede Local Government area of Nigeria. Those practicing folklore medicine prepare the leaves as tea to be drunk by hypertensive patients.

Other anti-infective agents

(a) *Piper guineense* is used in several traditional formulations to treat coughs, gastro-intestinal disorders, cold, bronchitis, venereal diseases, and rheumatism. It is also used as a spice in foods, in suppositories for its medicinal properties, and as a preservative in indigenous medicinal preparations. Several active principles have been isolated (Haensel and Zander, 1961; Haensel and Pelter, 1969; Okogun and Ekong, 1974).

(b) *Enantia chlorantha* is used traditionally for treating leprous spots, ulcers, and jaundice. It has been demonstrated that an aqueous extract was able to repair or reverse the liver damage produced in experimental rabbits (Bamgbose et al., 1979). This scientific observation is significant because it gives support to the widespread use of this plant in Nigeria as a cure for jaundice. Extracts of *Enantia* species, *Cryptolepsis sanguinolenta, Piper guineense, Xylopia aethiopica,* and *Azadirachta indica* are all effective for wounds, boils, and skin diseases. An infusion of bark powder of *Calotropis procera* is also used in the treatment of leprosy (pers. comm. with herbalists).

(c) *Ageratum conyzoides* is used in the tropics for the treatment of wounds and ulcers. In some places it is used for the treatment of gonorrhea. It has been shown that the fractions that showed great activity against *Staphylococcus aureus* were most effective in promoting wound healing (Adesogan, 1983).

Anti-convulsant

Solanaceous plant species have recently assumed great importance as a rich source of compounds that are precursors of steroid drugs. Steroidal raw materials have been found useful in cardiovascular therapy, as human arbotiacients, anti-inflammatory agents, and menopause regulants, and are known to influence the central nervous system (CNS) (Adesina et al., 1983). Alkaloids have been detected in *Solanum aethropicum, S. americanum, S. gilo, S. macrocarpon, S. melongena, S. torvum,* and *S. scabrum.* This finding confirms an earlier report that the bitter glyco-alkaloid solanine and its structurally related derivatives characterized the genus *Solanum.*

In moderate doses solanine and its breakdown products have sedative properties while solamargine possesses CNS depressant properties (Puri and Talata, 1964). The presence of steroidal alkaloids may be beneficial to the epileptic. The chemistry of 10 *Solanum* steroidal alkaloids has been comprehensively reviewed. They are known to exhibit some inhibitory or toxic action against organisms from all major taxonomic groups, from man to microbes. Various instances of illness and death of humans following ingestion of potato alkaloids have been reported in the last 100 years (McMillan and Thompson, 1979). Human toxicity symptoms include vomiting and diarrhea, anorexia, abdominal pain, confusion/delirium, hallucination, cyanosis, and coma. It should be stressed that the flesh of healthy potato tubers *(Solanum tuberosum)* normally contains a very small amount of alkaloids (much less than 20 mg/100 g fresh weight, which is the upper acceptable limit but at which tubers may taste bitter), which presents no hazard for the majority of the population. However, diseased and poorly stored (Jadhav et al., 1980), mechanically damaged, and light-exposed green or sunburned tubers accumulate large quantities, as do natural potato tuber extracts, leaves, and flowers of other *Solanum* and *Lycopersicon* species (Lampitt et al., 1943; Roddick, 1974). These compounds are not degraded by boiling or frying (Sizer et al., 1980), and in fact, tend to be concentrated by the latter process. However, it is ironic that if introduced today as a new food product, *Solanum tuberosum,* one of the major starchy staples of the world, would likely not be cleared by Food Standards Committees.

Death of livestock has been observed following ingestion of discarded *Solanum tuberosum* and *Lycopersicon* (tomato) foliage (Forsyth, 1968). Plans to feed livestock with waste tomato vines, which are relatively rich in protein, are hindered by the high *tomatine* content of the vines (Heftman and Schwimmer, 1972). Steroidal alkaloids elicit a variety of physiological responses in man; lethality is thought to result principally from the depression of CNS activity (Roddick, 1974).

The taxonomy of the genus *Solanum* in Nigeria has been investigated by the Forestry Research Institute of Nigeria; the occurrence of about 26 species has been reported (Gbile, 1983). Efforts should be made to evaluate the steroidal alkaloid contents with a view to selecting the best species for the industrial production of pharmaceutical steroids.

Laxatives

In 1977, about N1.5 million worth of laxatives was imported (Sofowora, 1982), despite the fact that Nigeria is rich in plants with laxative properties, including *Aloe, Cassia, Rhamnus, Momordica* and *Jatropha* species. *Cassia alata* has been found to combine antibiotic with laxative properties. *C. alata* has yielded anthracene derivatives, which are responsible for the laxative effect of the drug (Rai, 1978; Smith and Al, 1979). Vegetables like *Celosia, Talinum, Basella, Amaranthus, Vernonia, Allium,* and

fruits of *Carica papaya, Mangifera indica, Citrus,* and *Musa* species are sources of digestive plant oils, which are used as fecal softening laxatives.

CONCLUSIONS

The National Institute for Pharmaceutical Research and Development in Abuja is doing marvelously well in investigating some of the country's medicinal plants. The institute has developed NIPRISAN for the treatment of sickle cell anemia. Work is still in progress on the product.

The search for new medicinal products is being carried out by research scientists in various disciplines, including phytochemistry, pharmacology, pharmacognosy, chemistry, and botany. For the search to be meaningful, the need for various disciplines to integrate research programs cannot be stressed enough.

With the current rate of depletion of forest resources, Nigeria as a whole should be more conservation conscious. Efforts should therefore be made to establish medicinal plant gardens to serve as sources of raw materials needed for investigations into medicinal plants. Individuals and private organizations should also be encouraged to grow medicinal plants on their private farms.

REFERENCES

Adesina, S. K. 1976. Phytochemical studies of *Thaumatococcus daniellii* Benth. and *Dioscorephyllum cumminsii* (Stapf) Diels. Ph.D. thesis, University of Reading, England.

Adesina, S. K., Fasanmade, A. A. and Onowumi, I. M. 1983. Chemical investigation of some Nigeria Solanaceous plants used as anti-convulsants. Proc. VISOMP: 65–70.

Adesogan, E. K. 1983. Anti-infective agent of higher plant origin. Proc.VISOMP: 11–17.

Advisory Committee on Conservation. 1992. Natural Resources Conservation Action Plan. Final Report Vol. II. National Advisory Committee on Conservation of Renewable Resources i–iv.

Akinloye, B. A. and Adegbehin, J. O. 1984. Essential oils from Nigeria *Eucalyptus* species. The Nigerian Journal of Pharmacy 15(1): 11–14.

Attaway, J. A, Pieringer, A. P. and Barabar, L. J. 1966. The origin of *Citrus* flavour components. 1. The analysis of *Citrus* leaf oils Ms. Phytochemistry 5: 141–151.

Bamgbose, S.O.A., Adegoke, E. A., Adewoye, H. O. and Ogunwuyi, J. O. 1979. Effect of *Enantia chlorantha* in experimental liver damage. Preliminary report. J. of African Medicinal Plants 91.

Boakye-Yiadom, K. and Fiagbe, N. D. 1977. Anti-microbial properties of some West African Medicinal Plants IV. Lloydia 40(6): 453–545.

Connell, D. W. and Lachlan, R. M. 1972. National pungent compounds. J. Chron. 67: 29–31.

Ekung, D.E.U. and Ogan, A. U. 1968. Chemistry of the constituents of *Xylopia aethiopica.* The structure of Xylopia acid, a new diterpene acid. J. Chem. Soc. (c): 311.

Essien, E. E. 1985. Raw materials for the pharmaceutical industry in Nigeria and standardization for drug. The Nigerian Journal of Pharmacy 16(11): 34–38.

Forsyth, A. 1968. British poisonous plants. 2nd Ed. London: Her Majesty's Stationery Office.

Gbewonyo, W.S.K. and Addy, M.E. 1983. Further pharmacological studies on the anti-anaphylactic action of extracts of *Desmodium adscendens* (Sw.) DC. var. *adscendens*. Proc. of VISOMP: 46–53.

Gbile, Z. O. 1983. The Taxonomy and Ecology of Nigerian species of *Solanum* L. Ph.D. thesis. University of Ibadan.

Gbile, Z. O. 1994. Nigerian Medicinal Plant and Danger of Extinction. *In*: Conservation of Plant Genes II: Utilization of Ancient and Modern DNA, Adams, Miller, Golenberg and Adams, eds. Missouri Botanical Garden, St. Louis, Missouri.

Gbile, Z. O. and Adesina, S. K. 1987. Nigeria flora and its pharmaceutical potentials Journal of Ethnopharmacol 19: 1–16.

Haensel, R. C. and Zander, F. 1961. Longmans of Congo Cuberbs. Arch Pharm. 294–699.

Haensel, R. C. and Pelter, M. 1969. Relative and absolute configuration of Yangambin and Ashantin. Arch. Pharm. 302–940.

Heftmann, E. and Schwimmer, S. 1972. Degradation of tomatine to 36-hydroxy-5 &-Pregn-16-en-20-one by ripe tomatoes. Phytochemstry II: 2783–2787.

IUCN. 1987. The IUCN Directory of Afrotropical Protected Areas. IUCN, Cambridge, UK.

Irvine, F. R. 1961. Woody plants of Ghana. Oxford University Press.

Iwu, M., Oridoa, O. and Anazodo, M. 1986. The antimalarial activity of *Azadirachta indica*. Paper presented at the Workshop on Medicinal Plants. University of Ife.

Jadhav, S. J., Wu, M.T. and Salunkhe, D. K. 1980. Glycoalkaloid of hollow heart and black heart potato tubers. Hortscience 15: 147–148.

Kami, T., Nakayama, M. and Nayashi S. 1972. Volatila constituents of *Z. officinali*. Phytochemistry 11: 3377–3381.

Kefford, J. F. and Chandler, B. Y. 1970. The Chemical Constituents of Citrus Fruits. Academic Press, New York and London.

Kio, P.R.O. and Gbile Z. O. 1987. Problems of raw materials in pharmaceutical research. Paper delivered as guest lecturer at the annual meeting of the Nigeria Society of Pharmacognosy. University of Ibadan, Ibadan.

Kio, P. R. O., Gbile, Z. O., Soladoye, M. O. and Anozie, V. O. 1986. Some medicinal forest plants of Africa and Latin America. FAO Forestry Paper 241–245.

Lampitt, L. H., Dushill, J. H., Rooke, S. H. and Jackson, E. M. 1943. Solamine, glycoside of the potato II. Its distribution in the potato plant. J. Soc. Chem. Ind. 62: 48–51.

McMillan, M. and Thompson, J. C. 1979. An outbreak of suspected solanine poisoning in school boys. Quart. J. Med. N.S. 48: 227–243.

Murata T., Shinohara, M and Miyamoto, M. 1972. Isolation of hexahydrocurimin, dehydrogingerol and two additional pungent principles from ginger. Chem. Pharm. Bull. 20: 2291–2292.

Nigeria Conservation of Biological Diversity. 1988. World Conservation Monitoring Centre, Cambridge.

Obiorah, B. 1982. Tablet formulation using adjuvants of Nigeria origin. Pharmacy International 3(2): 54–56.

Odebiyi, O. O. and Sofowora, E. A. 1978. Phytochemical screening of Nigerian medicinal plants, II. Lloydia 41(3).

Okogun, J. I. and Ekong, D. E. U. 1974. Extract from the fruits of *Piper guineense*. J. Chem. Soc. Perkin Trans 1: 274.

Oliver, B. 1960. Nigeria's useful plants. Nigerian Field 25(4): 174–232.

Opakunle, W. O. 1983. The need for a national institute for pharmaceutical research. The Nigerian Journal of Pharmacy 14(6): 18–22.

Puri, S. G. and Talata, D. 1964. A survey of some plants used in native medicine of West Africa of interest to India. Paper presented in a symposium on Recent Advances in the Development, Production and Utilization of Medicinal and Aromatic Plants in India, p. 35.

Rai, P.P. 1978. Anthracene derivatives in leaves and fruits of *C. alata*. Curr. Sc. 47: 271–272.

Roddick, J. G. 1974. The steroidal alkaloid and tomatine. Phytochemistry 13: 9–25.

Sizer, C. E., Maga, J. A. and Craven, C. J. 1980. Total glycoalkaloids in potatoes and potato chips. J. Agri. Food Chem. 28: 578–579.

Smith, R. M. and Al, S. 1979. Anthraquinones from the leaves of *Cassia alata* from Fiji. New Zealand J. Sci. 22: 123–125.

Sofowora, A. 1982. Medicinal Plants and Traditional Medicine in Africa, John Wiley, Chichester.

Sofowora, E. A. and Isaac, W. A. 1971. Reversal of sickling and crenation of erythrocytes by the root extract of *Fagara zanthoxyloides*. Lloydia 34: 303.

Taylor, D.A.U. 1986. The chemistry of the Lemonoids from *Meliaceae*. *In*: Progress in the Chemistry of Organic National Products 45, 1–102. W. Stertz et al., eds. Springer-Verlag, New York.

THE MISSOURI BOTANICAL GARDEN'S DNA BANK

James S. Miller and Heidi H. Schmidt
Missouri Botanical Garden
P.O. Box 299
St. Louis, Missouri 63166-0299, U.S.A.

SUMMARY

The Missouri Botanical Garden has developed a collection of desiccated leaf material that is available for macromolecular phylogenetic studies. The collection currently contains more than 1100 fully processed and databased samples from 17 countries. Preserving samples specifically for molecular analysis provides material that is collected, processed, and stored in a manner that best preserves the chemical integrity of the sample. Furthermore, the collection helps alleviate the number of requests for destructive sampling of conventional herbarium material. Methods for curation of the collection are described, and the guidelines for distribution of material are also discussed.

INTRODUCTION

Systematics has traditionally been based on the study of morphological variation, and this continues with ever-increasing sophistication; study of biological macromolecules has played a major role in elucidating relationships in the latter half of the 20th century. As understanding of the molecular basis of inheritance increased, studies of directly heritable characters have assumed greater attention. Studies of variation of chromosome number and structure provided a valuable set of characters. The study of proteins by isozyme electrophoresis provided the first widely used method for comparative studies. Comparison of amino acid sequences was used to produce the first estimates of a molecular clock (Zuckerkandl and Pauling, 1962).

Studies of nucleic acids through hybridization, restriction enzyme analysis, or sequencing have more recently provided very powerful data sets for elucidating the relationships of organisms. Inferred sequences of the N-terminal 40 amino acids of the small subunit of RuBisCO (*rbcS*) were used in the first attempt of constructing a comprehensive overview of angiosperm phylogeny based on nucleic acid sequence data (Martin and Dowd, 1991); the study included representatives of 335 species from 122 families. Major advances in techniques for the isolation, purification, amplification, and analysis of DNA and RNA have led to increasing use of chloroplast, ribosomal, mitochondrial, and nuclear genes to generate phylogenies.

In plants, sequences of the chloroplast gene *rbcL* provided the first broad look at the relationships at the familial level (Chase et al., 1993). As molecular investigations of plant phylogeny have progressed, nucleic acids have been analyzed by a greater number of methods and a greater number of genes have been sequenced. In addition to *rbcL* (Rodman et al., 1996), *ndhF* (Terry et al., 1997), *matK* (Plunkett et al., 1996), and other chloroplast genes have been commonly studied in plants and have proven very useful for elucidating relationships. Although cpDNA has most recently been the genome of choice for most modern molecular phylogenetic studies in plants, ribosomal

RNA (Hamby and Zimmer, 1992), nuclear ribosomal DNA (Kim et al., 1996), nuclear DNA (Appels and Baum, 1992), and other genes have been used as well.

In addition to the increase in the number of genes studied and methods for their analysis, molecular studies have moved from the first broad taxonomic surveys (Martin and Dowd, 1991; Hamby and Zimmer, 1992; Chase et al., 1993) toward studies aimed at further resolving relationships with, rather than between, families or toward resolving the proper taxonomic placement of small families of uncertain affinity. It is by definition more difficult to obtain the necessary plant material for both of these types of studies. Detailed studies of relationships with plant families require access to material of the rare, seldom collected genera and taxa of uncertain affinity that are often poorly understood because they are represented in permanent collections by inadequate material. These difficult to obtain taxa are also those that are impossible to obtain from cultivated collections or other sorts of germplasm repositories.

It is precisely for these reasons that proactively gathered material will be important to ensure the unimpeded success of future molecular studies.

Rationale for the Missouri Botanical Garden Collection

As the study of macromolecules as systematic characters proceeds, the demand for material from which nucleic acids can be extracted is certainly increasing. Material for molecular study may be field-collected by the researcher or botanical collaborators and transported as fresh, frozen, or desiccated samples (Sytsma et al., 1993). In addition, appropriate samples can also be obtained from cultivated collections, seed banks, and by removal of material from herbarium collections (Sytsma et al., 1993; Miller, 1997). Although the methods for extracting material from herbarium specimens have improved dramatically, producing both higher quality DNA and requiring less leaf material (Jansen, 1998), those taxa most desired for study are often those with limited geographical ranges that are only infrequently encountered by collectors and are hence poorly represented in collections. While curators have generally allowed removal of small amounts of material for molecular analysis from herbarium specimens, they are often reluctant to allow material to be removed more than a single time, and often do not allow sampling of species represented in collections by less than five specimens, and certainly want to prevent excessive destructive sampling of collections (Wood et al., 1998). More recently, collections of material collected specifically to serve as a resource to support molecular phylogenetics have been established by a number of institutions, including the Missouri Botanical Garden (Miller, 1998), the Harvard University Herbaria (Wood et al., 1998), and the Royal Botanic Gardens Kew in Great Britain.

The advantages of proactively gathering samples from which nucleic acids can be extracted are numerous. Having material available for study eliminates the time waiting for plant collectors to respond, which can often be considerable. In fact, having plentiful material available of particular taxa may even suggest certain projects and ensure that they have a high chance of success.

Because proactively gathered material is prepared by methods specifically designed to ensure the preservation of DNA, the isolated DNA should be of higher quality than that isolated from material removed from herbarium specimens. Banked samples should also eliminate some of the pressure to remove material from herbarium

specimens. If the quantity of material gathered is adequate, it will also allow for multiple analyses of a particular sample, thereby facilitating repeated analysis, study of the same material by different labs, or study of additional genes.

CURATORIAL METHODOLOGY

Collection

Many authors have suggested that leaves of plants can be easily collected, preserved, and used later for macromolecular studies (Rogers and Bendich, 1985; Doyle and Dickson, 1987; Pyle and Adams, 1989; Liston et al., 1990; Sytsma et al., 1993; Miller, 1997). In addition, the methods for collection of leaf samples are simple and inexpensive. It requires only a minimal additional effort for botanists to gather samples from a percentage of encountered taxa, despite being already committed to other endeavors.

The method that Missouri Botanical Garden botanists have used for gathering samples is quite simple. For each sample collected, a high quality herbarium voucher (usually with several duplicates) is collected as a permanent record. Each sample consists of 4 to 10 g of leaf material placed in a 10 cm by 15 cm reclosable plastic bag with at least 10 grams of desiccant for each gram of leaf tissue. Adams et al. (1992) found silica gel and Drierite to be equally effective at desiccating samples, and botanists of the Missouri Botanical Garden have found the less expensive silica gel produced for the florist trade to be as effective as the more costly laboratory grades (Miller, 1997). Indicator crystals help ensure that only fully dry desiccant is used and help monitor drying of leaves. Attempts should be made to collect an adequate amount of leaf material to allow for multiple analyses. Small leaves should be collected whole, but leaves too large for the sample bags should be torn into appropriately sized pieces as this damages tissue less than cutting (Chase and Hills, 1991).

Processing

Before being intercalated into the permanent collection, samples are labeled and bar-coded, collection data are entered into the specimen database, and the desiccant is checked. While samples are awaiting labels, they are stored in numerical sequence by collection number for each collector so that they can be retrieved. Each specimen label clearly indicates that the collection is a voucher for a DNA sample and, in addition to the labels prepared for herbarium specimens and duplicates, an additional label is prepared for the sample. The 10 x 15 cm sample bags are used because they can be stored in standard bryophyte specimen storage cases and also because they can accommodate a standard specimen label. When labels are inserted into the sample packets, the samples are each bar-coded. This allows simple production of duplicate labels at a later time so that they can be distributed with requested material. Labels can also be photocopied as a means of distributing data, but bar codes allow a much more efficient means of generating data for large numbers of collections. At the same time that labels are inserted and samples are bar-coded, the desiccant should be checked. A small amount of completely dry desiccant ensures that the samples are maintained in proper condition and does not waste space in the storage cabinets.

Curatorial Storage

The Missouri Botanical Garden DNA collection is stored in the same standard file cabinets that are used to house the bryophyte collection, but the DNA sample cabinets are maintained in a -20° C walk-in freezer. Each cabinet has eight drawers and each can accommodate two rows of 50–75 samples, so each cabinet stores an average of

1000 samples. The collection is organized as five separate taxonomic groups: bryophytes, vascular cryptograms, gymnosperms, monocots, and dicots. Within each taxonomic group, samples are arranged alphabetically by family, with families separated by rigid, labeled cards to facilitate access. Within each family the samples are arranged alphabetically by genus and species. As most requests for samples are taxonomically based, this system allows for easy retrieval of related taxa.

CURRENT COLLECTION SCOPE AND USE

In the first few years since Missouri Botanical Garden botanists began collecting DNA samples, the number of collections has grown rapidly. The total number of fully processed and bar-coded samples with complete database records exceeded 1100 in 1997 and includes taxa from 162 families and 610 genera. The backlog of unprocessed material is probably equal in size to the fully curated collection. The samples presently available have been collected from 17 countries. In general, the families best represented are those that are large and widely distributed. Of the seven families with 25 or more samples (Table 1), only *Lauraceae* and *Annonaceae* have representation

Table 1. Seven families with 25 or more samples in the DNA bank.

Family	Number of samples
Fabaceae	55
Asteraceae	43
Rubiaceae	38
Rosaceae	32
Euphorbiaceae	28
Annonaceae	25
Lauraceae	25

somewhat disproportional to their size, and both reflect staff research interests. Sixteen genera are represented by five or more samples (Table 2). While the summary numbers in Tables 1 and 2 would indicate that representation is reflective of the size, distribution, and abundance of families and genera of plants, what they do not show is the number of taxa of limited distribution that are included in the collection. Of the nine families of flowering plants endemic to Madagascar, six are represented in the collection. Botanists collecting samples have made a concerted effort to include taxa with restricted geographic distributions, small families and small genera, and particularly taxa of uncertain taxonomic affinity.

In 1997, DNA samples of 17 species from five families were distributed from the banked DNA collection, compared with 28 species that were sampled from herbarium collections. All but one of six requests were for multiple taxa.

Guidelines for the Distribution of Material

Samples may be requested from the collection in writing or via the Internet. Information about access to the collection is available on the World Wide Web at http://www.mobot.org/mobot/research/DNAdocs/dnabank.html. Researchers requesting material must agree to a series of conditions (Appendix 1) and must sign and submit a material transfer agreement (Appendix 2) prior to release of material. Researchers requesting material are requested to register all sequences with GenBank, may not

distribute material to third parties without previous written permission, and are also requested to acknowledge both the Missouri Botanical Garden and the specific collector of the samples. While simple collection of material does not provide an adequate contribution for authorship of articles, researchers requesting material are asked to consider whether botanists who collected the material could provide additional

Table 2. Sixteen genera with five or more samples in the DNA bank.

Genus	Number of samples
Quercus	13
Ilex	10
Ocotea	9
Piper	9
Hypericum	8
Sorbus	8
Miconia	7
Pinus	7
Rubus	7
Vaccinium	7
Cordia	6
Psychotria	6
Rhus	6
Acer	5
Dichapetalum	5
Ipomoea	5

information and might be considered for co-authorship. Once these conditions have been met, material from the bank is distributed with duplicate specimen labels to ensure that researchers have a full record of all collection information.

CONCLUSIONS

We are currently in the middle of a renaissance of re-evaluating the relationships and classification of plants driven largely by the analysis of a variety of genes. As this work proceeds, the Missouri Botanical Garden's DNA bank, and other similar efforts, will play a critical role facilitating access to hard-to-obtain plant taxa. DNA banks of this sort provide ready access to high quality material while alleviating the need to destructively sample herbarium specimens, particularly of those taxa poorly represented in collections.

ACKNOWLEDGMENTS

W.D. Stevens and J.C. Solomon were instrumental in the development of the Missouri Botanical Garden's DNA collection; their encouragement and support is gratefully acknowledged. K. Ficken, B. Magill, and A. Tucker provided computer support. M. Merello has helped in many ways, ensuring that plant collectors had supplies for collections and also with processing of samples and their incorporation into the collection.

REFERENCES

Adams, R.P., Do, N. and Ge-lin, C. 1992. Preservation of DNA in plant specimens from tropical species by desiccation. *In*: Conservation of Plant Genes DNA Banking and *in vitro* Biotechnology R.P. Adams and J.E. Adams, eds. Academic Press, New York.

Appels, R. and Baum, B. 1992. Evolution of the *Nor* and *5SDNA* Loci in the Triticeae, *In*: Molecular Systematics of Plants, P. S. Soltis, D. E. Soltis and J. J. Doyle ed., Chapman and Hall, New York.

Chase, M.W. and H.H. Hillis. 1991. Silica gel: an ideal material for field preservation of leaf sample for DNA studies. Taxon 40: 215–220.

Chase, M.W., Soltis, D.E., Olmstead, R.G., Morgan, D., Les, D.H., Mishler, B.D., Duvall, M.R., Price, R.A., Hills, H.G., Qiu, Y.-L., Kron, K.A., Rettig, J.H., Conti, E., Palmer, J.D., Manhart, J.R., Sytsma, K.J., Michaels, H.J., Kress, W. J., Karol, K.G., Clark, W.D., Hedren, M., Gaut, B.S., Jansen, R.K., Kim, K.-J., Wimpee, C.F., Smith, J.F., Furnier, G.R., Strauss, S.H., Xiang, Q.-Y., Plunkett, G.M., Soltis, P.S., Swensen, S.M., Williams, S.E., Gadek. P.A., Quinn, K.J., Eguiarte, L.E., Golenberg, E., Learn, G.H., Graham, S.W., Barrett, S.C.H., Dayanandan, S. and Albert, V.W. 1993. Phylogenetics of seed plants: an analysis of nucleotide sequences from the plastid gene rbcL. Ann. Missouri Bot. Gard. 80: 528–580.

Doyle, J.J. and Dickson, E.E. 1987. Preservation of plant samples for DNA restriction endonuclease analysis. Taxon 36: 715–722.

Hamby, R.K. and Zimmer, E.A. 1992. Ribosomal RNA as a phylogenetic tool in plant systematics. *In*: Molecular Systematics of Plants, P.S. Soltis, D.E. Soltis and J.J. Doyle, ed., Chapman and Hall, New York.

Jansen, R.K. 1998. DNA sampling from herbarium material: a current perspective. *In*: Managing the Modern Herbarium D.A. Metsger and S.C. Byers, eds., Society for the Preservation of Natural History Collections (in press).

Kim, S.-C., Crawford, D.J. and Jansen, R.K. 1996. Phylogenetic relationships among the genera of the subtribe *Sonchinae* (*Asteraceae*): Evidence from ITS sequences. Syst. Bot. 21: 417–432.

Liston, A., Rieseberg, L.H., Adams, R.P., Do, N. and Zhu G-L. 1990. A method for collecting dried plant specimens for DNA and isozyme analyses, and the results of a field test in Xinjiang, China. Ann. Missouri Bot. Gard. 77: 859–863.

Martin, P.G. and Dowd, J.M. 1991. A comparison of the 18s ribosomal RNA and rubisco large subunit sequences for studying angiosperm phylogeny. J. Mol. Evol. 33: 274–282.

Miller, J.S. 1998. Banking desiccated leaf material as a resource for molecular phylogenetics. *In:* Managing the Modern Herbarium D.A. Metsger and S.C. Byers, ed., Society for the Preservation of Natural History Collections (in press).

Plunkett, G.M., Soltis, D.E. and Soltis, P.S. 1996. Evolutionary patterns in Apiaceae: Inferences based on *matK* sequence data. Syst. Bot. 21: 477–495.

Pyle, M.M. and Adams, R.P. 1989. *In situ* preservation of DNA in plant specimens. Taxon 38: 576–581.

Rodman, J.E., Karol, K.G., Price, R.A. and Sytsma, K.J. 1996. Molecules, morphology, and Dahlgren's expanded order Capparales. Syst. Bot. 21: 289–307.

Rogers, S.O. and Bendich, A.J. 1985. Extraction of DNA from milligram amounts of fresh, herbarium, and mummified plant tissues. Pl. Molec. Biol. 5: 69–76.

Sytsma, K.J., Givnish, T.J., Smith, J.F. and Hahn, W.J. 1993. Collection and storage of land plant samples for macromolecular comparisons. *In*: Molecular Evolution: Producing the Biochemical Data E.A. Zimmer, T.J. White, R.L. Cann, and A.C. Wilson, ed., Methods in Enzymology, Vol. 224, Academic Press, San Diego.

Terry, R.G., Brown, G.K. and Olmstead, R.G. 1997. Examination of subfamial phylogeny in Bromeliaceae using comparative sequencing of the plastid locus *ndhF*. Amer. J. Bot. 84: 664–670.

Wood, E.W., Eriksson, T. and Donoghue, M.J. 1998. Guidelines for the use of herbarium materials in molecular research. *In:* Managing the Modern Herbarium D.A. Metsger and S.C. Byers, ed. Society for the Preservation of Natural History Collections (in press).

Zuckerkandl, E. and Pauling, L. 1962. Molecular disease, evolution and genic heterogeneity. *In*: Horizons in Biochemistry M. Kasha and B. Pullman, ed., Academic Press, New York.

Appendix 1. CONDITIONS FOR THE RELEASE OF MATERIAL BY THE MISSOURI BOTANICAL GARDEN

The Missouri Botanical Garden maintains ownership of all plant material and releases samples only under specific conditions to support appropriate research projects. Samples in the Garden's DNA Bank have been collected solely for the purpose of supporting molecular phylogenetics and material will be released only for the study of relationships or plants or for studies aimed at improving our understanding of evolutionary mechanisms. Samples will not be made available for bioprospecting endeavors, screening for genes of interest in agricultural research, or any other commercial application.

A fee of $25 is charged for each sample requested and payment should be made to the Missouri Botanical Garden. This fee may be waived under certain circumstances, but only on approval of a request for a complete or partial waiver addressed to the Curator of the Herbarium, Missouri Botanical Garden, P.O. Box 299, St. Louis, Missouri 63166-0299, U.S.A.

As a condition of release for any samples specified on the attached list, each applicant agrees to abide by the restrictions stated above and also agrees to:

1) Register GenBank/EMBL accession numbers.

2) Acknowledge both the Missouri Botanical Garden and each individual collector of material provided in each publication in which data are used.

3) Publish jointly with Garden staff members or their foreign collaborators whenever appropriate.

4) Provide the Garden with reprints from all resultant publications.

5) All requests to pass either material provided by the Garden or extracted DNA to third parties must be approved, via a material transfer agreement, by the curator of the herbarium.

Appendix 2. MISSOURI BOTANICAL GARDEN DNA BANK MATERIAL TRANSFER AGREEMENT

The Missouri Botanical Garden maintains ownership of all plant material and releases samples only under specific conditions to support appropriate research projects. Samples in the Garden's DNA Bank have been collected solely for the purpose of supporting molecular phylogenetics and material will be released only for the study of relationships or plants or for studies aimed at improving our understanding of evolutionary mechanisms. Samples will not be made available for bioprospecting endeavors, screening for genes of interest in agricultural research, or any other commercial application.

A fee of $25 is charged for each sample requested and payment should be made to the Missouri Botanical Garden. This fee may be waived under certain circumstances, but only on approval of a request for a complete or partial waiver addressed to the Curator of the Herbarium, Missouri Botanical Garden, P.O. Box 299, St. Louis, Missouri 63166-0299.

As a condition of release for the samples specified on the attached list, each applicant agrees to abide by the restrictions stated above and also agrees to:

1) Register GenBank/EMBL accession numbers.

2) Acknowledge both the Missouri Botanical Garden and each individual collector of material provided in each publication in which data are used.

3) Publish jointly with Garden staff members or their foreign collaborators whenever appropriate.

4) Provide the Garden with reprints from all resultant publications.

5) All requests to pass either material provided by the Garden or extracted DNA to third parties must be approved, via a material transfer agreement, by the curator of the herbarium.

I _____(name) of _____ (institutional acronym) certify that I have read and understand the above restrictions and agree that I will conform to all of the regulations of the Missouri Botanical Garden.

Signature_____ Date_____

SURVEY OF LABORATORIES ENGAGED IN MOLECULAR BIODIVERSITY ANALYSIS OF PLANTS AND ANIMALS IN SUB-SAHARAN AFRICA

L. Guarino
International Plant Genetic Resources Institute
Sub-Saharan Africa Regional Office
P.O. Box 30677, Nairobi, Kenya
and I. Dawson
International Center for Research in Agroforestry
P.O. Box 30677, Nairobi, Kenya

SUMMARY

Using questionnaires designed to identify research activities, research gaps, and areas for possible collaboration, information from 19 laboratories carrying out molecular biodiversity analysis of plants and animals in sub-Saharan Africa was collected. Data collected from the questionnaires are presented here. The survey indicated considerable research activity within the region, with a majority of laboratories using a range of traditional and more modern techniques for molecular analysis. The level of collaboration between countries within the region was low, although most laboratories expressed a willingness to collaborate in training or research activities. Outside South Africa, constraints to research included a lack of availability of equipment and reagents, possibly reflecting a generally poor transportation and importation infrastructure within the region. Outside South Africa, research funding came mainly from international rather than national governmental sources.

INTRODUCTION

In the past few years, advances in molecular biology have resulted in the development of a number of powerful new DNA-based tools for assessing genetic variation in plants and animals (Avise, 1994), complementing longer-established approaches for the assessment of variation such as isozyme analysis (Tanksley and Orton, 1983). Techniques include restriction fragment length polymorphism (RFLP) analysis (Miller and Tanksley, 1990) and approaches based on the polymerase chain reaction (PCR) (Bachmann, 1994). PCR-based techniques, which include amplified fragment length polymorphism (AFLP) (Paul et al., 1996), random amplified polymorphic DNA (RAPD) (Williams et al., 1990; Dawson et al., 1996), RFLP-PCR (Tragoonrung et al., 1992; Dawson et al., 1996), simple sequence repeat (SSR) (Morgante and Olivieri, 1993), and single-strand conformation polymorphism (SSCP) (Orita et al., 1989) analyses, have found very wide application in recent years. These tools can be used to investigate a variety of key topics relevant for the conservation and sustainable use of plant and animal genetic resources, from phylogenetic to genetic linkage analysis, allowing the optimization of strategies for *in situ*, *ex situ*, and *circa situ* conservation.

A review has recently been published on the use of protein and DNA-based markers to analyze plant germplasm from sub-Saharan Africa (Dulloo et al., 1998). The survey involved a review of existing literature between the years of 1974 and 1995 on

the bibliographic CD ROM (PlantGene CD). In all, 146 studies were identified, covering 62 genera. The majority of studies involved cultivated crops and their wild relatives (107 studies). In all, 28 crop species were analyzed, 22 of which were native to Africa. Rice, sorghum, pearl millet, and *Phaseolus* were particularly well represented among crops studied. Thirty-nine studies were carried out on other (wild) species, with species native to South Africa being best represented. The majority of these studies considered individual species, or groups of related species, and did not consider ecosystem (e.g., forest, agricultural system) diversity as a whole.

Although it was difficult to identify the laboratories in which analysis was carried out, it was clear that the majority of studies were performed outside the sub-Saharan Africa region. With the high international interest in policy issues surrounding the ownership of plant and animal germplasm, developing countries are increasingly interested in the national characterization of plant and animal genetic resources contained within their boundaries. Consequently, the International Center for Research in Agroforestry (ICRAF) and the International Plant Genetic Resources Institute (IPGRI) decided to commission a survey of existing facilities for molecular biodiversity analysis within the sub-Saharan Africa region, with a view to documenting existing research capacity, research activities, research gaps, and possible areas for collaboration within the region. Laboratories carrying out research on plants and animals were included. Survey results are presented here.

SURVEY METHODS

In June 1996, questionnaires (Appendix 1) were sent to 34 laboratories or institutions in the region, each believed to be involved in molecular genetic evaluation of plants or animals. In each case, a list of laboratories to which questionnaires was sent was also provided, in order that respondents could identify other laboratories not on the original list.

The questionnaire was structured in order to obtain information within the following areas: (i) type of research, (ii) taxa studied, (iii) analytical techniques applied (PCR and non-PCR), (iv) institutional capacity for molecular research, (v) constraints limiting such research, (vi) collaborating institutions, (vii) potential for further collaboration (including training); and (viii) sources of funding (as shown in Appendix 1). In this way, it was hoped to obtain an overall picture of research activities, research gaps, and areas for collaboration in the region, while identifying common themes and limitations.

RESULTS

A total of 19 responses were received from 34 questionnaires sent (Table 1). Most responses (10) were from South Africa. Data are summarized in Table 2 and are considered further below.

Type of research

Most laboratories indicated involvement in more than one area of molecular genetic research. While 16 laboratories were involved in population genetic studies, 14 were carrying out phylogenetic research, and 9 performed genetic linkage analysis.

Taxa studied

Fifteen laboratories were carrying out research on plant taxa, while six focused on animal research. Nine laboratories worked on other organisms, including bacteria, fungi, and viruses.

Table 1. Summary of responses to a questionnaire addressing molecular biodiversity analysis of plants and animals in sub-Saharan Africa. Bracketed values indicate the number of questionnaires sent.

Country	Responses
Cameroon	1 (2)
Cote d'Ivoire	0 (2)
Ethiopia	0 (1)
Kenya	4 (5)
Mauritius	1 (1)
Niger	1 (1)
Nigeria	1 (1)
Senegal	0 (3)
South Africa	10 (17)
Tanzania	1 (1)

Analytical techniques applied

Laboratories applied a range of PCR-based and other techniques for analysis. Of the non-PCR-based techniques, 16 laboratories carried out RFLP analysis, 11 DNA sequencing, and 10 isozyme analysis. For the PCR-based techniques, figures were (number of laboratories in parenthesis): RAPD analysis (16); RFLP-PCR (13); SSR analysis (8); AFLP analysis (4); SSCP analysis (4).

Institutional capacity

Data on institutional capacity proved difficult to synthesize from completed forms, but one indication of the level of institutional facilities may be obtained from the presence or absence of radionucleotide detection facilities. Twelve laboratories had facilities for radioisotope detection.

Constraints

Thirteen laboratories indicated funding as a constraint to research, while eight identified the lack of availability to equipment and reagents as a constraint. Interestingly, only one laboratory in South Africa identified the latter as a constraint, possibly reflecting the more advanced transportation and importation infrastructure in that country. Several companies that market molecular biology equipment and reagents have offices in South Africa. Regionally, only one laboratory identified poor access to plant or animal material as a constraint for research.

Collaborating institutions

Except for one laboratory, all indicated collaborative links with other institutions. Excluding South Africa, all laboratories had collaborative links with institutions outside of Africa. Overall, however, only two laboratories indicated collaborative links with institutions in other African countries. In South Africa, most collaboration was with other organizations within South Africa.

Potential for further collaboration

While 14 institutions indicated the potential for further collaboration through the provision of training, 11 indicated possibilities through joint research projects, and 6 through the exchange of information.

Table 2. Summary of laboratories for molecular biodiversity analysis of plants and animals in sub-Saharan Africa.

Institute	Areas of Research	Taxa currently studied	Analysis, non-PCR	Analysis, PCR	Isotope facilities	Major constraints	Collaborators	Further collaboration? (purpose)	Source of funding
Cameroon									
University of Yaounde, Biotechnology Centre	- Fingerprinting - Other	- *Plasmodium falciparum* - *Mycobacterium tuberculasis*	- Isozyme - RFLP - DNA sequencing	- RFLP-PCR	yes	- Availability of equipment/reagents - Collaborators - Funding	- U. Georgetown (USA) - U. Uppsala (Sweden)	- Joint research projects - Exchange personnel - Give training	- International agency
Kenya									
Kenya Forestry Research Institute	- Population genetics - Phylogenetics - Genetic linkage analysis - Fingerprinting	- Conifereae - Leguminosae - Myristicaceae - Moringaceae - Rhizobium - Salicaceae - Verbenaceae - *Frankia* spp.	- Isozyme - RFLP - Seed protein	- RAPD - RFLP-PCR		- Availability of equipment/reagents - Funding - Government regulations	- National Museums of Kenya (Kenya) - Oxford Forestry Institute (UK) - Scottish Crop Research Institute (UK) - U. Dundee (UK) - U. Moi (Kenya) - U. Wageningen (Holland)	- Exchange of information, equipment and reagents - Give and receive training	- National governmental - International agency
International Livestock Research Institute	- Population genetics - Phylogenetics - Genetic linkage analysis - Fingerprinting - Other	- Bovidae - Forages (e.g. *Pennisetum* spp., *Sesbania* spp.)	- Isozyme - RFLP - DNA sequencing	- RAPD - SSR - SSCP - DNA sequencing	yes	- Collaborators	- Various universities - International Centre for Research in Agroforestry (Kenya)	- Joint research projects - Give training	- National governmental - International agency
National Museums of Kenya, Centre for Biodiversity	- Population genetics - Phylogenetics - Fingerprinting - Other	- Various mammals (e.g. Buffalo, Elephant, Gazelle, Rhinoceros, Zebra) - Tilapia - *Prunus africana* - *Saintpaulia* spp. - Sweet potato	- Isozyme - RFLP - DNA sequencing	- RAPD - RFLP-PCR - SSR	yes	- Availability of equipment/reagents - Funding	- ORSTOM (France) - San Diego Zoological Society (USA) - U. Mainz (Germany) - U. Case Western Reserve (USA)	- Joint research projects - Give training	- International agency
Tea Research Foundation of Kenya	- Population genetics - Phylogenetics - Genetic linkage analysis	- *Camellia* spp.	- Isozyme	- RAPD - RFLP-PCR - SSCP		- Availability of equipment/reagents - Collaborators - Funding - Trained personnel	- Scottish Crop Research Institute (UK)	- Joint research projects	- Industry
Mauritius									
Mauritius Sugar Industry Research Institute, Biotechnology Division	- Genetic linkage analysis	- *Saccharum* spp.	- RFLP	- RAPD		- Trained personnel	- CIRAD (France) - International Consortium of Sugarcane Biotechnology	- Exchange of information - Joint research projects - Give and receive training	- Industry

Table 2 *(continued)*

Institute	Areas of Research	Taxa currently studied	Analysis, non-PCR	Analysis PCR	Isotope facilities	Major constraints	Collaborators	Further collaboration? (purpose)	Source of funding
Niger									
ORSTOM, Laboratoire de genetique des plantes tropicales	- Population genetics - Phylogenetics	- *Pennisetum* spp.	- Isozyme - RFLP	- Possible 1997		- Availability of equipment/reagents - Collaborators	- CNRS, Montpellier (France)	- Joint research projects - Give training	- International agency
Nigeria									
International Institute for Tropical Agriculture, Ibadan and Onne laboratories	- Population genetics - Phylogenetics - Genetic linkage analysis - Fingerprinting - Other	- *Dioscorea* spp. - *Glycine* spp. - *Manihot* spp. - *Musa* spp. - *Vigna* spp. - Bacteria - Fungi - Plant viruses -Rhizobium	- Isozyme - RFLP	- RAPD - RFLP-PCR - SSR - AFLP - Other	yes	- Availability of equipment/reagents - Funding - Trained personnel	- John Innes Centre (UK) - U. Saskatchewan (Canada) - CIMMYT (Mexico) - CIAT (Columbia) - U. Bath (UK) - U. Tuskegee (USA) - U. Birmingham (UK) - U. Gent (Belgium) - USDA (USA)	- Exchange of information - Joint research projects - Give training	- International agency
South Africa									
ARC-Roodeplaat Vegetable and Ornamental Plant Institute	- Population genetics - Phylogenetics - Genetic linkage analysis - Fingerprinting	- Solanaceae - *Lachenalia* spp. - *Vitis* spp. - Cotton - Date palm - Horseradish - Onion - Pumpkin - *Fusarium* spp. - *Verticillium* spp - Nematodes	- Isozyme - DNA sequencing - RFLP	- RAPD - AFLP	yes	- Collaborators - Trained personnel	- ARC Tobacco and Cotton research Institute - UCT - South African Sugar Association Experiment Station	- Joint research projects - Give training	- National governmental - Industry
Institute for Tropical and Subtropical Crops	- Population genetics - Phylogenetics - Fingerprinting	- Avocado - Banana - Citrus - Litchi - Mango - Prickly pear	- Isozyme - RFLP	- RAPD - RFLP-PCR		- Funding	- Sister institutes (South Africa)	- Give training	- National governmental - International agency - Industry
Niervoorbig Institute for Viticulture and Oenology	- Population genetics - Other	- *Vitis* spp. - *Saccharomyces cerevisiae*	- RFLP - Other	- RAPD		- Funding	- U. Stellenbosch (South Africa)		- National governmental
Rhodes University, Department of Biochemistry and Microbiology	- Population genetics - Phylogenetics - Fingerprinting	- Dolphin - Fish - Honey bee - Ostrich - Proteaceae - Mycobacteria - Pleurotus	- RFLP - DNA sequencing - Other	- RAPD - RFLP-PCR - SSR - SSCP	yes	- Collaborators - Funding	- Port Elizabeth Museum (South Africa) - U. Rhodes - JLB Smith Institute (South Africa) - Chancellor College (Malawi) - U. Guelph (Canada)	- Joint research projects - Give training	- National governmental - Industry

Table 2 *(continued)*

Institute	Areas of Research	Taxa currently studied	Analysis, non-PCR	Analysis PCR	Isotope facilities	Major constraints	Collaborators	Further collaboration? (purpose)	Source of funding
South Africa (continued)									
South African Sugar Association Experiment Station, Biotechnology Department	- Population genetics - Genetic linkage analysis	- *Saccharum* spp. and hybrids	- RFLP - DNA sequencing	- RAPD - RFLP-PCR - SSR - AFLP - Other	yes	- Unknown long-term utility of approaches	- CIRAD (France)	- Exchange of information	- Industry
University of Cape Town, Department of Botany	- Population genetics - Phylogenetics	- Proteaceae - Melianthaceae - Restionaceae - Grasses - *Prunus africana*	- DNA sequencing	- RAPD	yes	- Collaborators - Funding			- National governmental
University of Cape Town, Department of Chemical Pathology	- Population genetics - Phylogenetics	- Bovidae - Felidae - Rhinocerotidae - Testudinidae - Equidae - Orchidaceae - Poaceae	- RFLP - DNA sequencing	- RFLP-PCR - SSR	yes		- Informal contacts overseas	- Exchange of information - Give training	- National governmental - International agency
University of Cape Town, Department of Microbiology	- Phylogenetics	- Sorghum - *Xanthomonas* spp.	- RFLP - DNA sequencing	- RAPD - RFLP-PCR	yes	- Funding	- International Crops Research Institute for the Semi-Arid Tropics (India) - U. Gent (Belgium)	- Joint research projects - Give training	- National governmental
University of the Orange Free State, Department of Microbiology and Biochemistry	- Population genetics - Phylogenetics - Genetic linkage analysis	- Pathogenic tree fungi - Propioniibacteria	- Isozyme - RFLP - DNA sequencing	- RAPD - RFLP-PCR - SSR - AFLP	yes	- Availability of equipment/reagents - Government regulations - Funding	- U. Stellenbosch (South Africa) - ISU, Ames (USA)	- Joint research projects	- National governmental - International agency - Industry
University of Pretoria, Department of Microbiology and Plant Pathology	- Population genetics - Phylogenetics	- Animals - Bacteria - Fungi - Viruses	- RFLP - DNA sequencing	- RAPD - RFLP-PCR	yes	- Funding - Access to plant material	- Veterinary Research Institute (South Africa)	- Exchange of material - Give training	- National governmental
Tanzania									
Sokoine University of Agriculture, Faculty of Veterinary Medicine	- Population genetics - Genetic linkage analysis	- Cattle - Chicken - Goat		- RAPD - RFLP-PCR - SSR - SSCP		- Availability of equipment/reagents - Funding - Trained personnel	- International Livestock Reseach Institute (Kenya) - Swedish U. Agriculture - CSIRO-MAGEC (Australia)	- Exchange of information, material and staff - Give training	- International agency

Sources of funding

Whereas 11 laboratories indicated the provision of funding through national governments, 10 indicated funding through international agencies and seven through industry. National government funding differed greatly between South Africa and the rest of the region. In South Africa, 9 institutions were supported by national government funding, whereas only 2 institutions in the rest of the region were supported by national government funding.

CONCLUSIONS

A survey performed by Dulloo et al. (1998), using PlantGene CD for the years 1974 to 1995, indicated that of the 146 molecular genetic diversity studies carried out on sub-Saharan Africa plant germplasm, few had been carried out within the region. The present survey, however, carried out in June 1996, indicates a considerable capacity for molecular biodiversity analysis of plants and animals within sub-Saharan Africa. One reason for the apparent discrepancy may be the relatively recent establishment of a number of laboratories, after Dulloo et al. (1998) survey. Although laboratories are carrying out work on a range of individual species, mostly to assess ecogeographical patterns of variation and phylogeny, little attention appears to be paid to the diversity of ecosystems as a whole. This apparent research gap needs to be addressed, possibly through collaborative projects involving a number of institutes studying a range of species with the same methodology.

Of the laboratories surveyed, the majority are using PCR-based technology as well as more traditional techniques based on RFLP and isozyme analyses. However, a serious constraint in the region (excluding South Africa) appears to be the availability of equipment and reagents. This is likely to be a particular issue for PCR-based approaches, which may rely on relatively advanced equipment and a range of labile reagents subject to extensive delays during importation. A further difference between South Africa and the rest of the region is the source of research funding. Whilst nine out of 10 South African laboratories receive a degree of government funding, only two out of nine laboratories in the rest of the region do so. This likely reflects the generally difficult funding situation for scientific research in the region, except for South Africa.

Although the majority of institutions surveyed identified collaborators outside Africa, only two indicated collaboration with institutions in other countries of Africa. Clearly, there is opportunity for increased collaboration within the region. The majority of institutions surveyed indicated a willingness to assist in training initiatives or joint research projects. It is to be hoped that in the next few years this desire will become a reality and that this survey will facilitate in this process by providing information to institutions on potential areas for collaboration.

REFERENCES

Avise, J.C. 1994. Molecular markers, Natural History and Plant Evolution, Chapman and Hall, New York.

Bachmann, K. 1994. Molecular markers in plant ecology. New Phytologist 126: 403–418.

Dawson, I.K., Simons, A.J., Waugh, R. and Powell, W. 1996. Detection and pattern of interspecific hybridization between *Gliriicdia sepium* and *G. maculata* in Meso-America revealed by PCR-based assays. Molecular Ecology 5: 89–98.

Dulloo, M.E., Guarino, L. and Ford-Lloyd, B.V. 1998. Genetic diversity studies of African germplasm using protein and DNA markers: a bibliography and review. Genetic Resources and Crop Evolution (in press).

Miller, J.C. and Tanksley, S.D. 1990. RFLP analysis of phylogenetic relationships and genetic variation in the genus *Lycopersicon*. Theoretical and Applied Genetics 80: 437–448.

Morgante, M. and Olivieri, A.M. 1993. PCR-amplified microsatellites as markers in plant genetics. The Plant Journal 3: 175–182.

Orita, M., Iwahana, H., Kanazawa, H., Hayashi, K. and Sekiya, T. 1989. Detection of polymorphisms of human DNA by gel electrophoresis as single-strand conformation polymorphisms. Proceedings of the National Academy of Sciences of the USA 86: 2766–2770.

Paul, S., Wachira, F.N., Powell, W. and Waugh, R. 1996. Diversity and genetic differentiation between Indian and Kenyan tea revealed by AFLP markers. Theoretical and Applied Genetics 94: 255–263.

Tanksley, S.D. and Orton, T.J. 1983. Isozymes in Plant Genetics and Breeding, Parts A and B Elsevier, Amsterdam, Holland.

Tragoonrung, S., Kanazin, V., Hayes, P.M. and Blake, T.K. 1992. Sequence-tagged-site-facilitated PCR for barley genome mapping. Theoretical and Applied Genetics 84: 1002–1008.

Williams, J.G.K., Kubelik, A.R., Livak, K.J., Rafalski, J.A. and Tingey, S.V. 1990. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. Nucleic Acids Research 18: 6531–6535.

Appendix 1.

Questionnaire on laboratory facilities for molecular marker analysis in sub-Saharan Africa.

A survey by the sub-Saharan division of the International Plant Genetic Resource Institute (IPGRI) and the International Centre for Research in Agroforestry (ICRAF), Nairobi, Kenya.

Please return completed questionnaires to: Dr Luigi Guarino or Dr Ian Dawson, c/o ICRAF, PO Box 30677, Nairobi, Kenya. Fax: +254 2 521 209 or +254 2 521 001. E-mail: ipgri-kenya@cgnet.com

1. Institutional information

Name of respondent	
Mailing address of institution	
Telephone/fax/e-mail	

2. Areas of research

For what purposes do you use molecular marker analysis?

- ☐Population genetics (e.g. measurement and partitioning of genetic diversity, analysis of mating systems, molecular ecology)
- ☐Phylogenetic studies
- ☐Genetic linkage analysis (e.g. mapping of important traits, marker-assisted breeding)
- ☐Other. Please specify:

3. Taxa studied

Please list taxa studied by molecular marker approaches in your laboratory		(cont.)

4. Molecular techniques used for the analysis of variation *(questionnaire continued....2)*

Which of these molecular techniques do you use for analyis?
☐ PCR ☐ Isozymes ☐ Seed proteins ☐ RFLPs[1] ☐ DNA-sequencing
☐ Other. Please specify:

If using PCR, please specify approaches
☐ RAPDs[2] ☐ RFLP-PCR[3] ☐ SSRs[4] ☐ SSCPs[5] ☐ AFLPs[6]
☐ Other. Please specify:

Do you use radioactivity for detection?
☐ No ☐ Yes. Please specify technique applied to, and isotope used:

Do you analyse data by computer?
☐ No ☐ Yes. Please specify software used:

5. Institutional capacity

Please provide some indication of the capacity of your laboratory facilities for molecular marker analysis. This could include the number and qualifications of resident staff, and the level of equipment available (e.g. number of gel rigs for isozyme analysis, number of PCR machines, facilities for radioactive work).

1 restriction fragment length polymorphism analysis.
2 random amplified polymorphic DNA analysis.
3 restriction fragment length polymorphism - polymerase chain reaction (or cleaved amplified product) analysis.
4 simple sequence repeat (or microsatellite) analysis, based at single defined loci.
5 single-strand conformation polymorphism analysis.
6 amplified fragment length polymorphism analysis.

6. Constraints *(questionnaire continued. 3)*

What, if any, are the major constraints for molecular marker analysis at your institution?

- ☐ Availability of reagents
- ☐ Availability of equipment (including spare parts and service support)
- ☐ Government regulations on use of chemicals
- ☐ Access to plant or animal material
- ☐ Shortage of personnel trained in the relevant disciplines
- ☐ Shortage of suitable collaborators in other institutions
- ☐ Shortage of funding
- ☐ Other. Please specify:

7. Collaboration

Do you collaborate with other institutions for molecular analysis[7]?

☐ No ☐ Yes. Please list the collaborators and specify the purpose of the collaboration:

Does your institution wish to develop collaborative links with similar laboratories in sub-Saharan Africa?

☐ No ☐ Yes. Please specify for what purpose:

[7] e.g. for the supply of plant or animal material for analysis, for the supply of equipment, for the supply or training of personnel or for carrying out molecular analysis itself (when institutional facilities are inadequate). Collaboration could involve advanced institutions such as universities from other countries.

8. Training *(questionnaire continued....4)*

Does your institute provide training in the area of molecular marker analysis?

☐ No ☐ Yes. At what level?

☐ Technician ☐ Degree or diploma ☐ MSc ☐ PhD ☐ Other. Please specify:

If carrying out training, where do trainees come from?

☐ Within institute ☐ Nationally ☐ Internationally ☐ Other. Please specify:

Is your institute willing to act as a resource for training in molecular marker analysis?[8]

☐ No ☐ Yes. Please specify how and in what circumstances:

9. Funding

How is molecular analysis funded at your institution?

☐National government funds.
☐Bilateral funds from a government donor agency.
☐Bilateral funds from a non-governmental organisation.
☐Multilateral funds (e.g. FAO, UNEP, development banks). Please specify.
☐Other. Please specify:

[8] e.g. by faciltating the exchange of staff between your and other institutes for training purposes, or by participating in regional training meetings.

10. Other information *(questionnaire continued 5)*

Please supply any further information which you think is appropriate for this study. This could include future work plans (technologies to be used and taxa to be assessed), concerns regarding the appropriateness or otherwise of molecular analysis in sub-Saharan Africa, and ideas for staff training. **If you are aware of other laboratories in sub-Saharan Africa carrying out molecular work, which are not included on the appended list, then please include addresses in this section.**

Appendix 2. Addresses of laboratories for molecular biodiversity analysis of plants and animals in sub-Saharan Africa.

REPLIES RECEIVED:

Cameroon

University of Yaoundé, Biotechnology Centre, Faculty of Science
P.O. Box 812, Yaounde, Cameroon
Fax: 237 234451 Tel: 237 237429 Contact: Professor Vincent Titanji

Kenya

Kenya Forestry Research Institute, P.O. Box 20412, Nairobi, Kenya
Fax: 254 154 32844 Tel: 254 154 32893/32484 Contact: Dr. Ebby Chagala
E-mail: ECHAGALLA@TT.SASA.UNEP.NO

International Livestock Research Institute, Naivasha Road, P.O. Box 30709
Nairobi, Kenya
Fax: 254 2 631 499 Tel: 254 2 630 743 Contact: Dr. Oliver Hanotte
E-mail: O.Hanotte@cgnet.com

National Museums of Kenya, Centre for Biodiversity
P.O. Box 40658, Nairobi, Kenya
Fax: 254 2 740122 Tel: 254 2 744233 Contact: Dr. Rashid Aman
E-mail: Raman@tt.sasa.unep.no

Tea Research Foundation of Kenya, P.O. Box 820, Kericho, Kenya
Fax: 254 361 20575 Tel: 254 361 20598/20599 Contact: Dr. Francis Wachira

Mauritius

Mauritius Sugar Industry Research Institute, Biotechnology Division
Réduit, Mauritius
Fax: 230 4541971 Tel: 230 4541061 Contact: Dr. Asha Dookun
E-mail: biologie@syfed-mu.mu.refer.org

Niger

ORSTOM, Laboratoire de génetique des plantes tropicales
B.P. 11416, Niamey, Niger
Fax: 227 722804 Tel: 227 753115 Contact: Dr. J.F. Renno; Dr. G. Bezancon
E-mail: renno@orstom.rio.net; bezancon@orstom.rio.net

Nigeria

International Institute of Tropical Agriculture, c/o. L.W. Lambourn and Co.
Carolyn House, 26 Dingwall Road, Croydon, CR9 3EE, England
Fax: 234 2 241 2221 (Nigeria); 44 181 681 8583 (UK) Tel: 234 2 241 2626 (Nigeria)
Contact: Dr. George Thottappilly; Dr. Hodeba Mignouna; Dr. Jonathan Crouch
E-mail: iita@cgnet.com

South Africa

ARC-Roodeplaat Vegetable and Ornamental Plant Institute, PB X293, Pretoria 0001, South Africa, Fax: 27 12 8081499 Tel: 27 12 8419611 Contact: Dr. J. Brink; Ms. A. Burger, E-mail: biojab@vopi.agric.za

Institute for Tropical and Subtropical Crops, PB X11208
Nelspruit 1200, South Africa
Fax: 27 13 7523854 Tel: 27 13 7532071 Contact: Dr. Ben Cilliers
E-mail: BEN@ITSC.AGRIC.ZA

Niervoorbig Institute for Viticulture and Oenology
PB X5026, Stellenbosch 7599, South Africa
Fax: 27 21 8895508 Tel: 27 21 8895500

Rhodes University, Department of Biochemistry and Microbiology
P.O. Box 94, Grahamstown 6400, South Africa
Fax: 27 461 24377 Tel: 27 461 318441 Contact: Professor Ralph Kirby
E-mail: MIRK@GIRAFFE.RU.AC.ZA

South African Sugar Association Experiment Station (SASEX), Biotechnology Department, PB X02, Mt. Edgecombe, Natal 4300, South Africa
Fax: 27 31 595406 Tel: 27 31 593205 Contact: Dr. Mornay Harvey
E-mail: mordave@icon.co.za

University of Cape Town, Department of Botany
PB, Rondebosch 7700, South Africa
Fax: 27 21 6503726 Contact: Dr. Nigel Barker
E-mail: dragon@botzoo.uct.ac.za

University of Cape Town, Department of Chemical Pathology
Medical School , Observatory, 7925, South Africa
Fax: 27 21 4066153 Contact: Professor Eric Harley
E-mail: harley@chempath.uct.ac.za

University of Cape Town, Department of Microbiology
PB, Rondebosch 7700, South Africa
Fax: 27 21 6897573 Tel: 27 21 6503263 Contact: Dr. Molapo Qhobela
E-mail: molapo@molbiol.uct.ac.za

University of the Orange Free State, Department of Microbiology and Biochemistry
P.O. Box 339, Bloemfontein 9300, South Africa
Fax: 27 51 4482004 Tel: 27 51 4012122 Contact: Professor B. Wingfield

University of Pretoria, Department of Microbiology and Plant Pathology
Agricultural and Biological Sciences, Pretoria 0001
Fax: 27 12 4203266 Tel: 27 12 4203622 Contact: Professor L. Nel
E-mail: Mikro1@scientia.up.ac.za

Tanzania
Sokoine University of Agriculture, Faculty of Veterinary Medicine
P.O. Box 3258, Morogoro, Tanzania
Fax: 255 56 3177/3275 Tel: 255 56 4647/4979/4980 Contact: Professor P. Gwakisa
E-mail: pgwakisa@sua.ac.tz

Other laboratories that may carry out molecular biodiversity analysis (questionnaire sent but no reply received):

Cameroon
CRBP, BP 832, Douala

Côte d'Ivoire
IDEFOR/DFO, 08 BP 33, Abidjan 08

Université de Abidjan, Départment de biologie végétal, 22 BP 582, Abidjan

Ethiopia
Addis Ababa University, Department of Biology, P.O. Box 3434, Addis Ababa

Kenya
International Centre for Insect Physiology and Ecology, P.O. Box 30772, Nairobi

Senegal
CIRAD-Forêt/ISRA/ORSTOM, Laboratoire de génetique et d'amélioration des plantes BP 1386, Dakar

Laboratoire commun ISRA/ORSTOM, Hann, BP 1386, Dakar

Université Cheik Anta Diop, Laboratoire de l'UCAD, Départment de biologie végétal BP 5005, Dakar

South Africa
Rand Afrikaans University, Research Unit for Aquatic and Terrestrial Ecosystems P.O. Box 524, Auckland Park 2006

Technicon OFS, Private Bag X20539, Bloemfontein 9300

Tobacco and Cotton Research Institute, PB X82075, Rustenburg 0300

University of Natal, Biochemistry Department, PB X01
Pietermaritzburg Scottsville 3209

University of Natal, Botany Department, PB X01
Pietermaritzburg Scottsville 3209

University of Natal, Genetics Department, PB X01
Pietermaritzburg Scottsville 3209

University of Natal, Molecular Biology Laboratory
Department of Zoology and Entomology, PB X01
Pietermaritzburg Scottsville 3209

RESEARCH AND TRAINING NEEDS IN CONSERVATION APPROACHES IN AFRICA

A. A. Oteng-Yeboah
Department of Botany, University of Ghana
P.O. Box 55, Legon, Ghana

SUMMARY

As a result of the decisions of the earth summit in 1992, some of which gave birth to the Convention on Biological Diversity, several challenges are being offered to state parties to the convention to ensure the smooth implementation of the provisions of the convention. Capacity building in almost every aspect of the conservation effort is seen to be very crucial. A review of the current situation in capacities and capabilities in Africa has been made as far as conservation of biodiversity in concerned. Research and training needs in inventories, curatorial works, domestication procedures, ethnobotanical searches, conservation education, monitoring bioprospecting ventures, and restoration procedures are seen as some of the crucial hurdles in capacity building that should be cleared to ensure smooth operation of conservation approaches in Africa.

INTRODUCTION

The UNCED meeting in Rio de Janeiro, Brazil, in June 1992, brought together heads of state and governments of over 170 countries to agree on guidelines to synchronize issues on the environment and development. Since then, there have been promising results globally.

In addition to having the Rio Declaration on Environment and Development, Agenda 21, and the Principles on Forests, two major international conventions were also negotiated and signed. The two conventions are on climate change and biological diversity.

The Convention on Biological Diversity (CBD) took effect on 29 December 1993 after the first 30 ratifications within only 18 months, which was unprecedented. The speed with which this happened underscored the widespread concerns the community of nations have about the rate of species extinctions that has resulted in a sense of urgency for quick action.

Fifteen African countries and three island states in the Indian Ocean were among the first 100 countries that ratified the convention. To date almost all the countries of the United Nations have ratified the convention.

The three main goals of the Convention on Biological Diversity are the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising out of the utilization of genetic resources. These goals are challenging. For nations that have ratified the convention, the conservation of biological diversity through the sustainable use of its components is expected to occupy the center stage of their development efforts in order to advance human development and environmental health and sanity.

Two main challenges have followed the rapid ratification of the convention. These are:

- the integration of the objectives of the convention into national strategies, policies, and programs as envisaged in Article 6 of the convention, and
- the elaboration through international cooperation of some of the key themes of the convention and the translation of these themes into options for action (Juma, 1995).

The creation of the Subsidiary Body on Scientific Technical and Technological Advice (SBSTTA) as provided for in Article 25 of the CBD has been worthwhile. It provides timely advice to the Conference of the Parties (COP) on the implementation of the convention, particularly on scientific, and technological matters. Thus, each member of the global community, particularly African countries, are expected to fully embrace and integrate the objectives of the Convention on Biological Diversity with their own national development goals. In doing this, they are expected to position their nations to ensure that facilities and or opportunities for implementing the objectives are in place in their countries. It is in this light that a review of the current situation on some aspects of biodiversity conservation in Africa is essential in order to project the areas that need strengthening.

CURRENT SITUATION IN AFRICA

There is a paucity of African taxonomists, thus affecting the search, collection, study, documentation, and management of data on Africa biodiversity. This is related to a lack of job outlets awaiting trainees in this specialization. There is a dearth of knowledge in general about the systematics of African plants, but in particular about the germination, seedling growth, and sapling maturity of indigenous African plants. Curatorial infra-structural development is lacking or in its infancy in Africa. With the exception of a few African countries that have national herbaria, museums, and botanical and zoological gardens, the majority of the African countries do not have these facilities. For countries with mycological, bacterial and viral repositories, there is virtually no information. There is also relatively little or no training and research in these areas, thus implying a lack of human resource development. The forests in many countries lack proper and effective management plans, which would involve monitoring and constant and regular assessment of stocks.

Those countries with management plans in place are not able to ensure their sustainability because of fiscal constraints and or misplacement of priorities. Following the adoption of the quick Economic Recovery Policies (ERP) in the early 1980s, such land use options as mining, logging, and agricultural and urban development activities have occupied the minds of African governments to the extent that pristine forests and biologically rich landscapes have been allowed to be destroyed. This has led to the loss of several ecologically important habitats and their inherent biodiversity.

As a result of a lack of bioprospecting policies, there is evidence of over-exploitation of biological resources, which leads to extinctions and loss of biodiversity. Excessive collection from the wild of biological resources that have recently been recognized for their usefulness as a source of economic value for food, medicine, etc., has rendered many species extinct, rare, or faced with extinction.

The paucity of African taxonomists

That there are fewer number of taxonomists in Africa south of the Sahara, excluding South Africa, has never been doubted. It has been noted in reviews in a

number of articles that relate the extent of knowledge of the African flora (Oteng-Yeboah, 1995a). The importance of the discipline of plant taxonomy to biodiversity considerations has been fully described, and eminent biologists have also expressed support that the discipline should not be neglected (Davis and Heywood, 1963; Egziabher and Edwards, 1987; Heywood, 1987; Oteng-Yeboah, 1991, 1992, 1993, 1994; Walters, 1987; Wilson, 1987).

The reasons for the paucity have been summarized as follows (Oteng-Yeboah, 1991):

- plant taxonomy curriculum in tertiary African institutions is inadequate, uninspiring, and too wide, thus creating negative responses in students.
- student attitudes toward field-oriented subjects are generally low key, because of inappropriate teaching methods used at the pre-university levels.
- lack of job opportunities/outlets for those who specialize in the discipline is a disincentive.

These reasons are the result of several years of observation in 4 African universities where the discipline has been offered for study and fewer students have been known to opt for it.

Strategies that may be needed to contain the situation are:

- to consider the kind of changes that may be required in the attitude of biology students in the tertiary institutions toward taxonomy. A certain amount of effort must be made to keep students interested in the subject. This calls for a review of the teaching of the subject, highlighting the easier and catchier aspects at the initial stages and presenting the more difficult and sometimes philosophical aspects in a subtle manner later. The attitude of students to field-oriented subjects needs to be looked into carefully. There may be a need to introduce incentives. University departments of biology with field programs should be adequately supported to take students to the field on a regular basis.
- to consider the kind of research that are performed by students. They must be relevant to current needs of the society or community.
- to consider the creation of job outlets and opportunities for specialists. Traditionally, the universities, research institutions, and specialized *ex situ* collection centers are the places where specialists in plant taxonomy would apply for jobs.

With university departments of biology being restricted to just one or two positions, research institutions having specific goals and orientations and therefore not showing interests in taxonomists, and the absence of these *ex situ* collection centers in many countries, job openings appear uncertain.

The dearth of knowledge of the African flora

This refers to the fact that there is lack of adequate knowledge on systematics and taxonomy, as well as autecological and synecological characteristics of indigenous African plants. Knowledge on the systematics and taxonomy of indigenous African plants, like in most developing parts of the world, remains at the pioneer stage, which is the first of a four-stage progressive development (Davis and Heywood, 1963). The pioneer stage generally takes care of identification, but even this task is not fully achieved as several species remain unidentified and others are yet to be discovered. The knowledge at this pioneer stage is uneven throughout Africa, as the flora in some places is better known than other places (Leonard, 1965, 1975; Hepper, 1968, 1979; Oteng-Yeboah, 1993).

We have no idea of the chromosome number and morphology of most African species. We have little or no idea about the breeding behavior of African plants. We do not have adequate documented information on how often and when indigenous African plants flower, fruit, set seed and flush their leaves, how their fruits and seeds mature, and when they are ready for germination. We have little or no information about the factors that promote the germination of seeds, the morphology and physiological characteristics of their seedlings, or how seedlings survive in their environments to become saplings.

We have little or no information of the factors that naturally operate to turn saplings into mature trees and shrubs in the natural forest ecosystem. Collection of seeds and or seedlings as materials for domestication (a field genebank *ex situ* conservation tool) or enrichment planting (as in *in situ* conservation situations) and the careful and conscientious effort to investigate germination rates, morphology, and survival rates in nurseries, and the growth rates, morphology and other ecological characteristics of the seedlings (wildings) and saplings either *ex situ* or *in situ,* and the phenological sequences of the mature shrub or tree, will provide the basic information required of indigenous plants. These processes will also offer the opportunity to provide the missing links or gaps in our understanding of the genetic and or breeding history through cytology and cytogenetic investigations of indigenous African plants.

Lack of curatorial infra-structural development

Very few African countries have national herbaria and botanical gardens with direct government funding, which could employ a large number of taxonomists involved in the normal curatorial works in these centers. A large number of African herbaria are part of university botany departments or forestry departments that serve the special or research interests of staff, and thus they have no national focus. In many of these herbaria, no research is even taking place. The few staff in these premises just routinely dust collections and sew back or repair detached specimens.

The situation of the botanic gardens is also pathetic. Botanical gardens in many African countries are, in actual fact, recreational parks for public outdoor activities or amusement, with their grounds filled mostly with exotic plant species. The gardens do not have a research orientation.

Ex situ depository/collection centers for fungi, viruses and bacteria are non-existent. Identification of difficult or unknown materials is usually done abroad, and presently these are done at exorbitant charges.

Thus as a result of little or no infra-structural development in the facilities for curatorial work on indigenous African plants, there is also a lack of human resource development. No skills in the handling of these aspects of biodiversity conservation are being taught.

Absence of forest estate management plans

It is known that forest ordinances ensure that a certain percentage of the land area of a country are considered as forest estate to ensure adequate protection of the biological wealth of the nation so that those that are yet to be studied could be documented at a later stage and exploited in a sustainable manner.

Many forest reserves in African countries indeed serve for timber production and exploitation, with a few in watershed areas, on slopes, and on very scenic or historical landscapes, protected for their very special floristic appeal and composition.

Because of the lack of discipline on the one hand, and greed on the other in many African countries, those forest estates that have no management plans have all been destroyed. Of those that have the management plans, many have not been able to ensure their sustainability because of fiscal constraints and or misplacement of priorities by the overseeing authorities.

There have been several instances in which government policies have shifted against forest estate conservation and preservation for other land use options. In the early 1980s when several African countries had shattered economies, several of these countries adopted the quick economic recovery programs (ERP) of the IMF and made these their policies. The result was the acceleration and extension of mining, logging, and agricultural activities into pristine forests and biologically rich landscapes. As a consequence, several ecologically important habitats and their inherent biodiversity have been destroyed and lost to mankind.

Lack of bioprospecting policies

Bioprospecting is an opportunity to add value to biodiversity. It is a new term but not a new concept. In the industrialized world, bioprospecting involves the chemical screening of plant/animal resources for "hits" that are considered useful in the worldwide pharmaceutical and chemical industries for drug development and discovery.

Bioprospecting thus involves a whole range of integrated actions such as inventorial studies (taxonomic and systematic), ethnobiological studies, reliable supply of extracts and chemicals for screening, mobilization of funds both at the local and external levels to pay for upfront expenses, serious negotiations between parties in the collections, screening and intellectual property rights of products, and an equitable and respectful dealing with the local or indigenous people.

No clear guidelines operate in the bioprospecting programs in many African countries. No policies exist as to the collection and export of raw materials, the legal protection of ethnobiological leads, and the compensation and/or royalties that may accrue on the event of any of the materials collected through ethnobiological leads and shipped, proving useful in *in vitro* trials and successfully developed into a drug.

The absence of bioprospecting policies leads to loss of opportunities for fair and equitable share in bioprospecting agreements and successes, and for the development of inventorial, extraction, and screening capacities and capabilities for national development. Surely this state of affairs will never enhance conservation efforts and sustainable use of biological resources.

GENERAL DISCUSSION

In the foregoing review, there is no doubt about specific research and training needs in conservation approaches in Africa. There is need for capacity building in all facets of conservation approaches in Africa. The capacity building is in both human and infrastructure, including policy development.

Inventorial and curatorial needs

As a result of the paucity of taxonomists and thus the dearth of knowledge of the African floristic heritage, inventorial and curatorial needs are paramount. The two needs, when addressed, will take care of the taxonomic impediments, which are the current drawback in biodiversity considerations in Africa (Oteng-Yeboah, 1995a, b).

During the second meeting of SBSTTA in 1996 in Montreal, the issues of inventorial and curatorial needs were considered, and these were endorsed at the third CoP of the CBD in Buenos Aeries, Argentina, as the Global Taxonomic Initiative, which is to be funded by the Global Environmental Facility (GEF). The idea behind this move is to develop and build capacities and capabilities in taxonomy in developing countries that are party to the Convention on Biological Diversity.

Domestication needs

Domestication is a tool in *ex situ* field gene bank conservation. It involves an understanding of the regeneration potentials of plant species in environments or sites other than that in which the plants have always been growing (Oteng-Yeboah, 1997).

Domestication is needed for several kinds of species for several reasons. The reasons include the alarming rates of habitat destruction, leading to loss of biodiversity through mining, logging, urbanization, and uncontrolled fires. In addition there is the unsustainable harvesting of resources from the wild either for economic gain for food, craft making, and export for medicine production, etc.

The species that need to be domesticated include:

- those that constitute the endemic floristic elements;
- those species currently known to be rare and or are under threat of extinction;
- those species with ethnobiological leads, which often end in drug discoveries and or as essential nutritional supplements; and
- those species whose constituents, through high-throughput screens, have become a potential source for a cure of certain globally important diseases such as AIDS and cancers.

All these species are indigenous and may never have been cultivated by man before. An understanding of the regeneration potential and the physical, chemical, biological, biochemical, and social characteristics of the environment in which the plant grows are essential. Tissue culture and other biotechnological methods are needed in these cases.

The biggest benefit that domestication can given to the African indigenous floristic heritage is the opportunity to enhance biodiversity conservation and the sustainable use of its components.

Ethnobotanical/Ethnobiological search

The Organization of African Unity Scientific and Technical Research Committee (OAU/STRC) has started efforts to document ethnobotanical information on African plants (OAU, 1985, 1986; Adjanohoun et al., 1991, 1993). It is an effort that can be enhanced when all nations in African are able to bring together their traditional herbal knowledge to provide the opportunities to document age-old information on uses of herbs for posterity.

Herbal medicine is big business and in order that there can be distinction between genuine academic exercise and exploitative tendencies, a system of gaining acceptance and confidence of the traditional herbal practitioners must be researched. The fears and aspirations of the healers must be allayed, appreciated, and forestalled, for a proper dialogue to emerge.

The information from the practitioners must be acknowledged and documented in such a way as to ensure that benefits can be routed to them whenever the information leads to a discovery.

If the information is used for commercial development, it will be important to obtain *a prior* informed consent from the community, and an effort should be made to ensure the offer of fair compensation for access to this information.

University departments should introduce courses in ethnobotany to teach undergraduates about plant uses by the local people. Post-graduate training in ethnobotany should be encouraged to develop skills for the collection and assemblage of traditional knowledge on biological resources.

There is a wealth of knowledge accumulated over the years in the traditional set up, which can be tapped only when the custodians of such knowledge are identified and can be persuaded to release it. Sometimes the knowledge is with the herbalists, other times it is with the family/clan heads, chiefs, farmers, and the older members in the community. In countries where the traditional systems are well organized, it is easy to make contacts.

Training in the search for traditional knowledge, particularly on the conservation and use of biological resources, is very much needed. All the establishments that have the capacity to assist in this endeavor should be expected to provide assistance.

Conservation education needs

The idea of excessive collection of forest products from the wild must be discouraged. This means that all identifiable groups of people, particularly those who live near the forests in the rural areas and whose economic well being depends on collections from the wild, must be approached and educated on conservation.

Several of these collectors are young and have no idea that when a resource is collected far beyond its natural potential to increase or regenerate, it may well become depleted and completely eliminated.

Many of these collectors need to be informed that only sustainable harvesting methods would enable them to remain in business. Several countries have Environmental Protection Agencies (EPA) whose activities include public education seminars. Aspects of conservation education need to be included in the training.

Occasionally, the forest and wildlife personnel must provide public education seminars to educate the public on their activities and complement the efforts of the EPA staff to ensure environmental health of forests and the wildlife resources of their countries. These officers will need to be trained on conservation education methods to be able to offer training to the public.

Monitoring needs

The institutions responsible for the protection of the forests and their products and wildlife resources, which together constitute biodiversity of a nation, must have a place for monitoring procedures. For effective monitoring, there must be adequate knowledge of the resources and their status. This means that when a particular resource is seen for some time, an attempt must be made to investigate a restoration process. When something new springs up in the environment, it must be recorded and observed for its influence, either positive or negative, to the environment.

These suggestions are the ideal. In the present difficulties as faced by several African countries in logistics for travel, trekking, and even for clothing for protection, a training in discipline and dedication for conservation objectives and goals must be made to sink deep into the hearts and minds of the officers.

The traditional structure in many African societies enforces compliance of dictates on wild lands (notably the fetish/traditional groves), through taboos and other sanctions. Many of these have broken down now, but a few are still in existence in West Africa. In societies where these have broken down, conservation education is needed so that the younger people understand the need to be cautious in extracting excessively from the wild. When the young are properly educated in these matters, they can even become vanguards in monitoring for conservation purposes.

Bioprospecting needs

Three inventorial needs must be properly satisfied for bioprospecting. These are: taxonomic inventories, ecological inventories, and ethnobotanical inventories. Taxonomic inventories will consider identification and other nomenclature issues; ecological inventories will require observations on ecological interactions among species such as between plant and herbivore, predator and prey, host and parasite; and ethnobotanical inventories access the use of traditional knowledge of local/indigenous rural communities. These inventories will ensure sound bioprospecting.

When a nation has inventorial capacity and capability, it means that it can control all the documentation procedures in bioprospecting. If the nation has the capacity to turn raw biological materials into extracts and these extracts can be reliably supplied, then the major components in bioprospecting have also been secured. The value of biological products at this stage is much higher than at the raw material stage.

This would have involved the nation's chemists and biochemists capable of extractions and biological assay procedures. Having an extract, whose composition is only known to the supplier, means that whenever it shows an activity against any of the world's dreaded diseases, the pharmaceutical or chemical company has no option but to revert to the supplier of that extract. Thus, if tests prove the extract is active and the product is developed into a drug, the extract supplier can commmand a large royalty. This is the model INBio Costa Rica has been able to fashion for itself, and which has helped in returning profits to the country, and in encouraging the conservation and sustainable use of biological resources among the rural folks.

Restoration needs

For degraded landscapes to be useful in enhancing conservation efforts, restoration and or rehabilitation capacities and capabilities must be in place. Different levels of degradation require different approaches to solve, so the processes of identification and application of solutions, and the biological material to be used must be adequately researched, understood and properly applied.

The solution for degradation as a result of surface and/or illegal mining is very different from those of other land uses. The land degradation from surface mining involves the removal of the whole topsoil including vegetation. For its restoration there is a the need to understand how to recreate a new topsoil that would allow a succession of new serial vegetation structures. Thus basic and applied research methodologies and training in restoration processes are urgently needed to heal the already degraded landscapes in Africa.

CONCLUSIONS

This paper has been an attempt to highlight the research and training needs in conservation approaches in Africa. It has not been completely exhaustive. Surely several other aspects of inputs very relevant in conservation should be known, documented, and researched to enhance conservation efforts.

It is believed that if these concerns and several others not mentioned here are carefully embraced, the implementation deadlines that may be set at the global level for the achievement of good environmental management would be fully met by African parties to the Convention on Biological Diversity; and that these nations would ensure that the conservation of biological diversity through the sustainable use of its components has indeed occupied the center stage of their national development efforts and goals.

REFERENCES

Adjanohoun, E., Ahyi, M.R.A., Ake-Assi, L., Dramane, K., Elewude, J.A., Fadoju, S.O., Gbile, Z.O., Goudote, E., Johnson, C.L.A., Keita, A., Morakinyo, O., Ojewole, J.A.O., Olatundji, A.O. and Sofowora, E.A. 1991. Traditional Medicine and Pharmacopoeia. Contribution to Ethnobotanical and Floristic Studies in Western Nigeria, Pub. OAU/STRC, Lagos, Nigeria.

Adjanohoun, E., Ahyi, M.R.A., Ake-Assi, L., Alia, A.M., Amai, C.A., Gbile, Z.O., Johnson, C.L.O., Kakooko, A.B., Lutakome, H.K., Morakinyo, O., Mubiru, N.K., Ogwal-Okeng, J.W. and Sofowora, E.A. 1993. Traditional Medicine and Pharmacopoecia. Contribution to Ethnobotanical and Floristic Studies in Uganda, Pub. OAU/STRC Lagos, Nigeria.

Davis, P.H. and V.H. Heywood. 1963. Principles of Angiosperm Taxonomy, Oliver and Boyd, Edinburgh.

Egziabher, T.B.G. and S. Edwards. 1987. Systematic botany—a key science in the study of tropical plant ecology. *In*: Systematic Botany—a Key Science for Tropical Research and Documentation, Inga Hedberg, ed. Symbolae Botanicae Upsalienses XXVIII (3).

Hepper, F.N. 1968. Regional synthesis. *In*: Conservation of Vegetation in Africa South of the Sahara, Inga and Olov Hedberg, ed. Acta Phytogeographica Suecica 54, Uppsala.

Hepper, F.N. 1979. Africa. *In:* Systematic Botany, Plant Utilization and Biosphere Conservation, Inga Hedberg, ed. Almqvist and Wiksell International, Stockholm.

Heywood, V.H. 1987. Tropical taxonomy—who are the users? *In:* Systematic Botany—a Key Science for Tropical Research and Documentation, Inga Hedberg, ed. Symbolae Botanicae Upsalienses XXVIII (3).

Juma, C. 1995. The new phase in the implementation of the convention, Bulletin on Biological Diversity. United Nations, Geneva, GE 95-03258.

Leonard, J. 1965. Statistiques des progres accomplis en 10 ans dans la connaissance de la flore phanerogamique africaine et Malgache (1953–1962). Webbia 19: 869–875.

Leonard, J. 1975. Statistiques des progres accomplies en 1 ans dans la connaissance de la flore phanerogamique africaine et Malgache (1953–1973). Boissiera 24: 15–19.

OAU/STRC. 1985, 1986. Organization of African Unity, Scientific Technical and Research Commission. African Pharmacopoeia, Vols. I & II Lagos, Nigeria.

Oteng-Yeboah, A.A. 1991. Plant Taxonomy—a neglected science in the third world. Ghana Science Association 17th Biennial Conference, UST, Kumasi, Ghana.

Oteng-Yeboah, A.A. 1992. Knowing Ghana's biodiversity: the first step in conservation, preservation and reservation practices. *In:* Proceedings of the Workshop on Biodiversity, E. Laing et al., ed. Botany Dept., Legon.

Oteng-Yeboah, A.A. 1993. Strategies towards increased knowledge of the African biodiversity. International Conference on the Convention on Biological Diversity: National Interests and Global Imperatives, ACTS, Nairobi, Kenya.

Oteng-Yeboah, A.A. 1994. DNA bank depositories in developing countries: the way forward. *In*: Conservation of Plant Genes II : Utilization of Ancient and Modern DNA, R.P. Adams et al., ed. Missouri Botanical Garden, St. Louis, Missouri.

Oteng-Yeboah, A.A. 1995a. Inventory needs in Ghana. *In*: Final Compendium for a Practical Workshop on Biodiversity Prospecting for Cameroon, Madagascar, and Ghana, INBIO, USAID & BCDP.

Oteng-Yeboah, A.A. 1995b. Biodiversity prospecting in Ghana: urgent issues to consider, Joint 19 Biennial Ghana Science Association and 15 Biennial West African Science Association Conference, University of Cape Coast, Ghana.

Oteng-Yeboah, A.A. 1997. *Ex-situ* conservation of indigenous African plant biodiversity, BDCP/ICS/UNIDO Course on Bioprospecting and Strategies for Industrial Exploitation of Medicinal Plants, Enugu, Nigeria.

Walters, S.M. 1987. The purpose of systematic botany. *In*: Systematic Botany—a Key Science for Tropical Research and Documentation, Inga Hedberg, ed. Symbolae Botanicae Upsalienses XXVIII (3).

Wilson, E.O. 1987. The biodiversity crisis: a challenge to science. *In*: Systematic Botany—a Key Science for Tropical Research and Documentation, Inga Hedberg, ed. Symbolae Botanicae Upsalienses XXVIII (3).

CONSERVATION OF MEDICINAL PLANTS: SELECTING MEDICINAL PLANTS FOR RESEARCH AND GENE BANKING

J. N. Eloff
Department of Pharmacology,
University of Pretoria, Pretoria, 0001 South Africa
e-mail: jneloff@medic.up.ac.za

SUMMARY

One of the reasons for conserving plants is that plants may be important for future human populations, and these potential uses are lost if the plant is lost to extinction. The medicinal use of plants is one of the most important potential uses. The development of prescription medicines and the difference in orthodox and herbal or natural medicine is discussed. The difference in research and development between the synthetic chemical and the natural product approach is also discussed. Two out of three people on earth use plants for their primary health care. Research and development can do much to improve the use of plants for primary health care. More scientists and pharmaceutical companies are investigating plants to search for compounds that can be used as prescription drugs for diseases that are not yet treatable and for diseases where orthodox drugs are becoming less efficient. One problem is to prioritize the 250,000 higher plants species on earth. Some of the parameters that influence the decision for research and conservation purposes are: ethnobotanical leads and conditions when ethnobotanical leads are valuable, the quantity of material used in the natural medicine trade, the use of the plant, pharmacological activity in related taxa, availability of plant material, and cooperators. There are three different strategies for conservation: *in situ* (original location), *ex situ* (grown away from natural area) and *in vitro* (conserving DNA). Additional factors that influence the choice of plants for conservation are biotechnological implications, conservation status of species/population, and pharmacological, taxonomical, and ecological implications. These parameters were applied to plants growing in the KwaZulu-Natal area of South Africa and the Hyascintacaceae family. The species in the genera *Drimia, Eucomis, Scilla,* and *Urginea* have the highest priority for research and conservation.

WHY SHOULD WE CONSERVE PLANTS?

There are two general motivations for conserving plants. Some people would argue that humans have a strong moral and ethical responsibility to conserve plants. This is especially true because the explosion of human population numbers and the development of human technology has led to a dramatic increase in the rate of extinction of plant species. These plant species have developed over eons and within a few hundred years large numbers have become extinct. In the recent past, we have lost half of tropical forests, and the remaining areas are being destroyed at a rate of 1.25% per year. Madagascar used to have at least 8000 plant species with more than 7000 endemic species. Madagascar has lost 93% of its virgin tropical forests (Miller, 1992).

Another argument is that plants are extremely valuable to man and that we can not afford to lose these plants and the novel chemicals that plants contain. Besides

using plants as food, a source of chemicals in industry, insecticides, molluscicides, flavors, etc., a major benefit of plants for the human race is for medicinal purposes. In this presentation the use of plants for medicinal purposes and the parameters that should play a role in selecting plants for research and conservation are discussed.

SOURCES OF MEDICINE

Evidence has been found that even Neanderthal man used plants for medicinal purposes. This is not surprising because dogs and cats eat grass and vomit if they do not feel well. It has been proposed that chimpanzees control their parasite-related diseases when they are sick by eating a bitter plant (*Vernonia amygdalina*) containing sesquiterpene lactones that are active against internal parasites. The Old Testament also refers to the use of plants for healing people (Ezekiel 47: 12). The first list of plants with instructions on use, i.e., a pharmacopoeia discovered in Thebes in Egypt, dates back to 1555 B.C. Many of the plants listed are still in use according to the British Pharmaceutical Codex.

Originally, supernatural influences were seen as the cause of disease. It took many centuries before it was accepted that diseases are caused by natural phenomena. This discussion still continues to some degree today. It is interesting to speculate that one could consider that diseases are mainly caused by natural phenomena and that illness (i.e., not feeling well) is caused by natural and/or psychic influences.

In the Middle Ages there were two approaches to cure diseases such as syphilis. Paracelsus was a driving force in promoting the use of chemicals, and Galen supported the use of plants. (The term galenical refers to a remedy made of vegetable not synthetic origin.) Neither group had much success. It was only after Ehrlich, with his magic bullet theory, developed a chemical compound, and Koch and Pasteur developed our understanding of microorganisms that this disease could be controlled.

The debate on whether a single synthetic compound or a mixture of compounds present in an extract is the best medicine continues in some circles today.

TREATING PRESENT ILLNESSES

How do we treat illnesses? The response to this question may be quite different if the question is put to an inhabitant of developing countries vs. an inhabitant of developed countries. There is also a difference in philosophy. Orthodox medicine (i.e., western, or medicine using synthetic compounds) is more inclined to treat diseases where there is a specific causative agent that may be combated with varying degrees of success. In orthodox medicine much attention is also given to lifestyle diseases. The most important component of alternative medicine is herbal or natural medicine. The emphasis is more on treating the physical aspects of an illness. But mental factors may also play a role in illness.

Developing countries

According to estimates of the World Health Organization, 3.3 million people in developing countries use medicinal plants for their primary health-care needs (Farnsworth, 1994). At that stage the estimated human population was 5.2 million. At least two of every three people on earth depend on plants directly to maintain their health. This figure does not include the millions of people in the developed countries who also use herbal medicines. In developing countries the diseases treated with herbal medicines focus on gastrointestinal problems, inflammation, dermatological ailments, and obstetric/gynecological disorders (Cox, 1994).

Developed countries

In developed countries, people mainly use well tested and controlled chemical compounds or mixtures. Even in this case medicinal components originally from plants still play an important role in conventional western medicine. In 1984, Farnsworth, et al. identified 119 secondary plant metabolites that are used globally as drugs. In 1984, at least 25% of the prescription drugs issued in the United States and Canada were derived from or modeled after plant natural products (Farnsworth, 1984). In orthodox medicine the most important diseases treated with plant-derived drugs are cardiovascular or nervous system disorders, and neoplasms or infections (Cox, 1994).

Back to nature

There is a widespread trend of "going back to nature" as the negative (or purported negative) effects of highly refined foods, pesticides, and herbicides on human health and the environment is realized. This is based on the widely held, but not necessarily correct, assumption that natural is better. With the increasing cost of medicine, more people are also looking at alternative medicine. The Eastern holistic approach of treating the whole person and not the disease *per se* also finds more acceptance with people suffering from many stress-related disorders. Robbins (1997) calls the escalating commercial demand for medicinal plants used in dietary or nutritional supplements in the United States the rebirth of natural medicine. The United States medicinal herbal industry was estimated at U.S. $1.6 billion (Brevoort, 1995) and consisted of ca. 1400 plant species.

Loss of activity of orthodox medicine

The indiscriminate use of antibiotics has led to drug resistance of many bacterial strains. It is thought the emergence of antibiotic resistance by bacteria has become a medical catastrophe; we may be entering a "post-antibiotic" era where antibiotics are no longer effective. Development of new anti-microbial compounds for resistant organisms is becoming critically important (Leggiadro, 1995). In 1967, 58% of all antibiotics were produced by Actinomycetes, 18% by other fungi, 12% by higher plants, 9% by bacteria, and the remaining 3% by algae, lichens, and animals (Edwards, 1980). In addition to searching for anti-cancer and anti-AIDS drugs, investigating plants for effective anti-microbial components should have a high priority.

DIFFERENT APPROACHES TO RESEARCH ON PLANT MEDICINAL COMPONENTS

The scope of the research approach depends on the resources available as well as on the philosophical background and terms of reference of the different organizations. It is understandable that the approaches of major pharmaceutical companies, government agencies, and organizations such as the World Health Organization (WHO) differ. The approaches may also change when the macro socio-economical situation changes.

The synthetic chemical approach

After the discovery of antibiotics and the development of synthetic chemical techniques, thousands of chemicals were synthesized and tested on animals. Large pharmaceutical companies have more or less ignored natural plant products for the past

few decades in favor of synthesizing novel compounds. At one stage there was an idea that drugs could be designed to interact with the receptor in the test organism, but this hope has not been realized. The wide approach followed by most major pharmaceutical companies is to synthesize chemical compounds based on (a) chemical compounds in existing medicines, (b) structure-function hypotheses, or (c) biologically active compounds found in plants.

This chemical approach is very labor intensive and expensive because you have to screen by using a whole barrage of biotests. The hit rate for biological activity can be very high, but few compounds pass the stringent tests. According to Vagelos (1991) Merck Pharmaceutical found that for every 10,000 chemical compounds evaluated in a battery of bioassays, only 20 are selected for animal testing. Of these 20 compounds, 10 will be evaluated in humans and only one will be approved by the Food and Drug Administration in the United States.

It takes about 12 years at a cost of U.S. $231 million to get a new drug on the market (Vagelos, 1991). Farnsworth (1990) identified the following additional stumbling blocks for the pharmaceutical industry:

1. No drugs can be patented if there is a prior disclosure in the scientific literature. Patent protection also starts with the beginning of drug development and not with marketing of the drug.
2. If the drug is derived from a plant long used in folk medicine, there is an additional patent problem.

The hit rate for synthetic chemical compounds has declined. Whereas it was ca. 20 per year in 1966, it is now less than one novel clinically important compound per year (Couzinier and Mamatas, 1986). This fact as well as the realization that many plant components with potential value to man may be lost with the high rate of species extinction in the tropical rain forests caused the National Cancer Institute of the United States to re-introduce its plant program in 1986 (Cragg et al., 1994).

THE NATURAL PRODUCT APPROACH

It has been estimated that 14–28% of higher plant species are used medicinally, but only 15% of all angiosperms have been investigated chemically, and 74% of the pharmacologically active plant-derived components were discovered following up on ethnomedical use of the plant (Farnsworth & Soejarto, 1991). Southern Africa contains ca. 10% of the world's plant diversity, but little work has been done on medicinal plants from this region. Of the 300 plants investigated by Noristan, 31% showed marked activity, 48% were moderately active, and 21% were inactive (Fourie et al., 1992).

The development of medicine has gone through phases with more or less attention paid to naturally occurring compounds. According to Farnsworth (1990) the last useful plant drugs to be discovered were vinblastine in 1960 and vincristine in 1963. The National Cancer Institute in the United States screened 32,000 higher plant species over a period of 30 years for their ability to inhibit various tumors. Of these 32,000 species, 7% possessed activity and several hundred active compounds were discovered. Of the 20 agents eventually evaluated in man, none was effective and/or safe enough to be marketed. This has caused major companies and even government research institutions in the west to move away from investigating plant derived medicines. Only ca. 1 novel clinically effective anti-cancer or anti-viral drug was obtained per 10,000 species examined (Cragg et al., 1994). Since 1986, new and more sensitive *in vitro* bioassay techniques were developed for cancer and AIDS. In 1992, taxol from the bark

of the Pacific yew, *Taxus brevifolia,* was approved as a drug to treat ovarian and breast cancers. More than 26,000 plant species were investigated in this ongoing program by the NCI and very promising results were obtained. A random selection of plants tested for activity against AIDS had a hit rate of 6%, and plants used in ethnomedicine for other ailments had a hit rate of 25% against AIDS (Balick, 1990). Subsequent de-replication (i.e., removing compounds such as tannins and polysaccharides that may be active, but are not useful) indicated that there were no differences (Balick, 1994).

Plant-based approach

A narrower approach is to examine a medicinally important plant for all the chemical components in the plant. But because there are thousands of different chemical components in a plant, this is still a major undertaking. Expertise in different fields of organic chemistry is required, and a wide range of biotests are required This approach is followed by major scientific institutions in China and India. If the action of the plant is based on psychological and not physiological activity, this may be a futile exercise.

Plant and bioassay guide fractionation approach

If a plant is used for a specific ailment and a low-cost *in vivo* or *in vitro* test to screen for the activity exists (or can be developed), the chance of success increases. The screening test is then used to follow the fractionation process qualitatively and quantitatively. This approach is followed in many smaller laboratories. The limiting factor here is the screening test. Even if a compound that is active in the plant is discovered, it still may not lead to a medicine if it is too toxic, too unstable, less effective than known medicines, or already used as a medicine.

HOW CAN RESOURCES BE USED TO BENEFIT PEOPLE?

An approach that has, understandably, not been followed to any great extent in western medicine is to utilize poorly defined plant preparations as medicine. The situation is very different in China and some other Eastern countries. In 1978, the World Health Assembly (WHA) of the World Health Organization (WHO) called for a comprehensive approach toward medicinal plants. This approach would include:

- scientific criteria and methods for assessing the safety of medicinal plant products and their efficacy in the treatment of specific conditions and diseases and
- the designation of research and training centers for the study of medicinal plants.

In 1987, the WHA urged member-states to:

- initiate comprehensive programs for the identification, evaluation, preparation, cultivation, and conservation of medicinal plants used in traditional medicine and
- ensure quality control of drugs derived from traditional plant remedies by using modern techniques, and applying suitable standards and good manufacturing practices.

In 1988 health professionals and plant conservation specialists reaffirmed their commitment to the collective goal of "health care for all by the year 2000" through the primary health care proposed in the Chiang Mai declaration. In addition, they called on all people to commit themselves to "save the plants that save lives." They made the following statements:

- we recognize that medicinal plants are essential in primary health care, both in self-medication and in national health services;

- we are alarmed at the consequences of the loss of plant diversity around the world;
- we view with grave concern the fact that many of the plants that provide traditional and modern plants are threatened;
- we draw the attention of the United Nations, its agencies and member-states, other international agencies, and their members and non-governmental organizations to:
  - the vital importance of medicinal plants in health care;
  - the increasing and unacceptable loss of these medicinal plants due to habitat destruction and unsustainable harvesting practices;
  - plant resources in one country are often of critical importance to other countries;
  - the significant economic potential of the medicinal plants used today and the great potential of the plant kingdom to provide new drugs;
  - the continuing disruption and loss of indigenous cultures, which often hold the key to finding new medicinal plants that may benefit the global community;
  - the urgent need for the international cooperation and coordination to establish programs for conservation of medicinal plants to ensure that adequate quantities are available for future generations.

WHICH PLANTS SHOULD WE RESEARCH OR CONSERVE?

Are ethnobotanical leads valuable?

The question of whether ethnobotanical leads are valuable in identifying medicinal components in plants has been discussed by various authors. Balick (1990) found that when screening plants for anti-HIV activity, there was a much larger percentage activity in plant species collected from ethobotanical leads than from plant species collected randomly. When the results were de-replicated by removing compounds such as tannins and polysaccharides, there was no difference (Balick, 1994). Cox (1994), who used a much larger database, also did not find any difference in testing for anti-HIV activity. It is however possible that significant compounds may be discarded in the de-replication process because some of these compounds are known to have immuno-stimulatory activity.

Ethnopharmocological leads should be much more valuable in cases where short-term results could be expected. Ethnobotanical leads should still be very important in identifying plants with potential use. Cox et al. (1989) found that 86% of the Samoan traditional herbal medicine had pharmacological activity. Fourie et al. (1992) investigated 300 South African plant species based on use as folk medicine. Only 21% of the plant extracts were inactive. There was a good correlation between the frequency of use and the pharmacological activity. Especially with analgesic, anti-inflammatory, anti-ineffective, and anti-ulcer properties, which are easily diagnosed by traditional healers, there was a clear clustering of activity and frequency of use.

Which ethnobotanical leads are useful?

Cox (1990) identified parameters that influence the value of ethnobotanical leads:

1. The culture should have a conservative ethnobotanical tradition with accurate transmission of information from one generation to the next.
2. The people should live in an area with a high species diversity.
3. The inhabitants should have inhabited the same area for many generations.

Information from such an area would be analogous to human bioassay data especially relating to diseases that are easily diagnosed and in which results are seen

soon. If people living in widely separated areas use the plant for the same reason, it is much more likely that the plant is valuable. According to these parameters the KwaZulu-Natal area in South Africa should yield trustworthy information. Substantial information has been collected and analyzed, especially by Hutchings et al. (1996).

WHICH PARAMETERS SHOULD BE CONSIDERED IN CHOOSING PLANT SPECIES FOR RESEARCH?

Is a plant used singly or as part of a mixture?

Chan (1995) indicated complications if medicinal plants are used as part of a mixture. This factor has inhibited the development of Chinese traditional medicine because mainly mixtures are used. Even when only one taxon is investigated the situation is very complex. Current pharmacological and biological tests are not very appropriate research on complex mixtures of natural substances, especially as many of them act on chronic symptoms (Anton et al., 1986). Synergistic or antagonistic factors may also play a role.

In contrast to the situation in China where mixtures of plants are widely used, Cunningham (1990) found that only four mixtures are commonly sold in traditional medicine markets in KwaZulu-Natal. These mixtures did form quantitatively the largest part of the market with an annual use of 350 metric tons. The mixture consisted of the following plants: *Maesa lanceolate, Hippobromus pauciflorius, Adenia gummifera, Urginea sp., Drimia sp., Foeniculum vulgare, Berkheya spp., Clivia miniata, Clivia nobilis, Harpephyllum caffrum, Ekebergia capensis, Rapanea melanophloeos, Protorhus longifolius, Sclerocarya birrea, Combretum kraussii, Zanthoxylum davyi,* and *Sideroxylon inerme.*

What quantity of the plant is used?

If quantitative data are available, this also is an important component that should be considered. Higher quantities used indicates the value of the plant, but availability also plays a role. Cunningham (1990) provided quantitative data on the use of medicinal plants in KwaZulu-Natal. In an effort to quantify the data, it was accepted that the mixtures consisted of the same quantity of each of the components. This is most probably incorrect, but it should provide some information on the quantitative use of the plants. The results obtained for plants that form a part of a mixture should be considered with circumspection and is indicated with a "ca." in Table 1. In the same table observations on the use of the plants from Watt and Breyer-Brandwijk (1962) and Hutchings et al. (1996) are also presented.

Farnsworth and Soejarto (1991) stated that at least 137 plant species are collected in the wild or cultivated in ton quantities. The 39 species listed here are all used in quantities in excess of one ton per year, which indicates that the use of medicinal plants in KwaZulu-Natal is high.

What are the clients willing to pay?

Because market forces play a role, price should be an indication of the value of the plant to the customer especially because the market is not skewed by modern marketing procedures. If a plant becomes overexploited, gatherers will have to search

Table 1. Medicinal plants used in KwaZulu-Natal for purposes calculated from Cunningham (1990).
Commentary Watt and Breyer-Brandwijk (1962) and Hutchings et al. (1996).
Use indicated in metric tons per year (ca. as part of a mixture, exact usage value uncertain).

Plant	Family	Use	Commentary
Hippobromus pauciflorius	*Sapindaceae*	ca. 49.2	eye problems, diarrhea and dysentery, emeticum, analgesic, influenza, catarrh, poisonous
Maesa lanceolate	*Myrsinaceae*	ca. 49.2	wounds, emeticum, antihelminthic, febrifuge, sore throats, jaundice, infertility, sting rash, vermifuge, toxic
Clivia miniata & C. nobilis	*Ammarillidaceae*	ca. 47.7	snakebite, fevers, induce childbirth, urinary problems, toxic
Scilla natalensis	*Liliaceae*	38.7	enemas, purgative, induce childbirth, boils, veld sores
Adenia gummifera	*Passifloraceae*	ca. 36.9	emetic, tonic, stimulant, malaria, chest pains
Rapanea melanophloeos	*Myrsinaceae*	ca. 35.2	heart problems, palpitations, acidity, stomach and muscular pains, expectorant, emetic, enema
Eucomis autumnalis	*Liliaceae*	29.1	enema, urinary diseases, fever, colic, flatulence, hangovers, syphilis, coughs
Alepidea amatymbica	*Umbelliferae*	26.0	colds, coughs, influenza, rheumatism, styptic, sore throats
Albizzia adianthifolia	*Leguminosae*	21.2	eczema, eye inflammation, headaches, sinusitis, stomachache, toothache, dysentery, haemorrhoids, purgative
Combretum kraussii	*Combretaceae*	ca. 20.2	tonic, appetite stimulant, enema, wounds
Sideroxylon inerme	*Sapotaceae*	ca. 20.2	emeticum, astringent, conjunctivitis, hernia, coughs
Zanthoxylum davyi	*Rutaceae*	ca. 20.2	coughs, colds, tonics, infected wounds, sore throats, mouth ulcers, boils, toothache, pleurisy, bilharsia
Ekebergia capensis	*Meliaceae*	ca. 18.8	emeticum, abscesses, boils, pimples, disinfectant, headaches, dysentery, skin ailments, parasiticide
Harpephyllum caffrum	*Anacardiaceae*	ca. 18.8	emetic, skin problems, rashes
Protorhus longifolius	*Anacardiaceae*	ca. 18.8	emetic, heartburn, bleeding from stomach, depilatory
Sclerocarya birrea	*Anacardiaceae*	ca. 18.8	malaria, diarrhea, heart, blood cleansing, abdominal pain, proctitis, fevers, headaches, ulcers, toothache, backache
Pentanisia prunelloides	*Rubiaceae*	17.2	haemorrhoids, snakebite, rheumatism, burns, stomach pains, tuberculosis, swellings, sore joints, palpitations, boils
Gunnera perpensa	*Halorrrhagiaceae*	17.0	cystitis, rheumatic fever, colic, cancerous sores, psoriases

Table 1 (continued). Medicinal plants used in KwaZulu-Natal.

Senecio gregatus	*Compositae*	17.0	enema, venereal diseases
S. serratuloides	*Compositae*	17.0	infections, sores, blood purifier, burns, swollen gums, chest pains
Dioscorea sylvatica	*Dioscoreaceae*	16.3	blood problems, chest complaints, parasites
Warburgia salutaris	*Canellaceae*	15.8	expectorant, rheumatism, malaria, sores, colds, coughs, venereal diseases, constipation, stomach ulcers
Bersama stayneri	*Melianthaceae*	14.8	barrenness, impotence, menstrual pain, leprosy
B. tysoniana	*Melianthaceae*	14.8	barrenness, impotence, menstrual pain, leprosy
Kalanchoe crenata	*Crassulaceae*	14.2	sprains, swellings, fevers
Berkheya spp.	*Compositae*	ca. 13.9	coughs, emetics, abdominal disorders, schistosomiasis, sore eyes, urinary complaints, sores, abscesses, burns
Drimia sp.	*Liliaceae*	ca. 13.9	chest pains, stomach ailments, high blood pressure, colds, expectorants, emetic
Foeniculum vulgare	*Apiaceae*	ca. 13.9	influenza, diuretics, jaundice, diarrhea, stomachache
Urginea sp.	*Liliaceae*	ca. 13.9	rheumatism, gout, bronchitis, asthma, hoarseness, influenza, diuretics, abdominal pains, swellings, demulcent
Bowiea volubilis	*Liliaceae*	12.9	abortions, dropsy, sore eyes, skin diseases, bladder pain
Trichilea dregeana & T. emetica	*Meliaceae*	12.6	stomach complaints, backache, kidney problems, blood cleanser, lumbago, intestinal worms, dysentery
Turbina oblongata	*Convolvulaceae*	12.5	arthritis, gout, spine pain, sores, abscesses, rheumatism
Rhoicissus tridentata	*Vitaceae*	12.2	renal complaints, sterility, epilepsy, stomach ailments, menorrhagia, indigestion
Bulbine latifolia	*Liliaceae*	12.0	eczema, syphilis, enemas, emetics, anti-spasmodic
Ocotea bullata	*Lauraceae*	11.7	urinary complaints, headaches,
Stangeria eriopus	*Cycadales*	11.7	emetic, headaches, purgative, flatulence, blood pressure
Anemone fanninii	*Ranunceae*	11.4	emetic, biliousness, colds, headaches, toothache
Cryptocarya myrtifolia & C. latifolia	*Lauraceae*	11.4	chest ailments, cramps, urinary tract problems, uterine spasms, menstrual pain
Eucomis bicolor	*Liliaceae*	11.2	purgative

more to collect the plant, will charge more for the plant, and, if another cheaper plant does not fill the need, customers will be willing to pay more.

For what are the plants used?

By considering only the quantity of plant material sold and the price, major mistakes can be made. In areas with a high incidence of lightning, many plants are bought to ward off lightning. Many plants are used also for magical purposes. In evaluating ethnobotanical leads, the disease for which it is used should be kept in mind. If there is a short response time between dosage and effect, the use is probably more reliable. The ethnobotanical approach is most likely to succeed where the focus is on diseases where healers use specific plants. According to the NAPRALERT database (Farnsworth, 1990), medicinal plants are used for a large number of medical conditions. The 11 conditions for which more than 1000 records have been recorded are: induce menstruation (4110), induce abortion (2630), reduce inflammation (1879), prevent post-partum hemorrhage (1547), cure bacterial diseases (1521), induce diuresis (1327), reduce fevers (1299), treat impotency (1275), reduce pain (1255), use as a contraceptive (124), and use as a laxative/cathartic (1032).

Diseases such as hepatitis, diabetes, diarrhea, gastrointestinal problems, skin infections, fungi, and wounds are most likely to be successfully treated (Balick, 1994). Cultural differences may also lead to problems in communication. It has been noted that *Croton sonderianus* was used for contraception purposes. After a project was started it was found that a long stick of this plant is used by the woman to hit the amorous husband to discourage him during her fertile period.

Do closely related plants have pharmacological activity?

There is frequently a strong correlation between the presence of plant secondary components in taxonomically related taxa. A related taxon may contain similar or related pharmacologically active components. It is worthwhile to conduct a literature search and then apply the information before deciding which plants to collect.

According to Balick (1990) the *Apocynaceae*, *Euphorbiaceae*, *Menispermaceae,* and *Solanaceae* families contain high concentrations of biologically active compounds on a worldwide basis. The families for which more than 10 metric tons were used in KwaZulu-Natal were calculated (data of Cunningham, 1990) and presented in Table 2. It is interesting that although all the families listed by Balick (1990) (*Apocynaceae*, *Euphorbiaceae*, *Menispermaceae,* and *Solanaceae*) occur widely in KwaZulu-Natal, not one of them are present among the top 24 families quantitatively used in the KwaZulu-Natal area according to these results.

How easily are the plants available?

It is extremely important that the identity of the plant be accurately determined. This is more difficult than many non-taxonomists would believe. A phytochemist would blithely with complete confidence use a name given by a botanist whereas there may be differences of opinion between different botanists. A name given to a taxon is an opinion of a person. If he is an expert and a flora of the area has been well developed or the plant occurs widely, many people would be able to relate to which plant is intended. The use of proper voucher specimens cannot be stressed enough. Therefore, plant material bought from a herbal trader and then analyzed may provide non-reproducible results if the identity and even the origin of the plant material is not 100% certain. It is preferable that the plant material should be from plants growing in the wild

Table 2. Total quantity of medicinal plants in different families used per year in KwaZulu-Natal (calculated from data of Cunningham, 1990).

Family	Total	Family	Total
Liliaceae	131.7	*Combretaceae*	20.2
Myrsinaceae	84.4	*Rutaceae*	20.2
Anacardiaceae	56.4	*Sapotaceae*	20.2
Sapindaceae	49.2	*Rubiaceae*	17.2
Compositae	47.9	*Halorrhagidaceae*	17.0
Amarillidaceae	47.7	*Dioscoreaceae*	16.3
Umbelliferae	39.9	*Canellaceae*	15.8
Passifloraceae	36.9	*Crassulaceae*	14.2
Meliaceae	31.4	*Convolvulaeae*	12.5
Melianthaceae	29.8	*Vitaceae*	12.2
Lauraceae	23.1	*Cycadales*	11.7
Leguminosae	21.2	*Ranunculaceae*	11.4

because the concentration of secondary products may vary depending on the environmental conditions.

Other factors should be considered. Plant parts should be healthy because attack from a pathogen will alter the concentration of certain secondary components drastically. The time of the year plant material is collected is also important, especially with deciduous plants. The type of plant, plant part, and scarcity of the plant all play a role in the ease with which plant material can be obtained. It is much easier to obtain leaves of a tree or the bulb of a plant that flowers once a year with obvious flowers than an ephemeral plant that grows in an arid area and completes its life cycle within weeks. The quantity of material available also plays a role. It will be more difficult to obtain sufficient material of the seed or bark of a threatened plant. Plants propagated in botanic gardens or in specialized nurseries such as the Silverglen Nature Reserve of the Durban Corporation in Chatsworth can help in this regard.

Is anybody else working on the same group of plants?

A major problem for people working on medicinal plants is collecting and identifying the plants. If a taxonomist is revising a group of plants, there is an excellent opportunity for cooperation because the taxonomist would have plant material available and the chemical data may help the taxonomists in circumscribing the taxa. There is also an excellent opportunity of cooperating with chemists specializing in different chemical components that are active.

Pragmatic approach

In a small laboratory a pragmatic approach could be followed. By focusing on a bioassay procedure or a specific plant, small laboratories could also add to the knowledge base of medicinal plants, although the chance that such a small laboratory could discover a valuable future prescription drug is negligible. A major problem is the tremendous duplication that must be taking place. Major companies do not make their results known both for possible future patent reasons and for not wanting to help the competition.

In our laboratory we have decided to investigate anti-microbial components due to the ease of the bioassay and the existing expertise. The plants we investigated first were identified as plants with a high potential by Dr. T.G. Fourie, a scientist who worked on the Noristan plant program. When the plant program was terminated, this work could not be continued. We have streamlined the extraction and bioassay procedures. We have found many anti-microbial components in the two plants that we first investigated *Anthocleista grandiflora* and *Combretum erythrophyllum*.

WHICH PARAMETERS SHOULD BE CONSIDERED WHEN CHOOSING PLANT SPECIES FOR CONSERVATION?

Conservation strategies

The two strategies for the conservation of plants are *in situ* and *ex situ* conservation. For *in situ* conservation, the focus is on conserving the ecosystem as a whole. *Ex situ* conserved plants are grown outside their natural environment in botanic gardens. The third possibility could be called *in vitro* conservation. In this case plant material containing the genetic code for all the chemical components in the plant are conserved under conditions where the DNA could be recovered and the original plant material regenerated at a later stage.

For certain tissues in many plants this is already possible. With the development of biotechnology this should eventually become possible for most plants. If technology develops to such a stage that a plant could be regenerated from dried plant material, the herbaria of the world, which house millions of plant specimens collected over centuries, will be resources of inestimable value.

The parameters listed below are pertinent to conservation of medicinal plants for all three strategies.

Biotechnological implications

The question of how the material collected should be preserved is a separate issue that has been addressed elsewhere.

The type of material to collect for preservation is also important. In general the less differentiated the plant tissue is, the easier it would be to re-establish plants from this material at a later stage. With today's technology it is usually impossible to regenerate plant material by tissue culture from highly differentiated tissue such as bark or seed coat. As a general guideline the plant material should contain meristimatic tissue. Plant parts used in propagation of plants in conventional horticulture, such as seed, bulbs, tubers, and rhizomes always contain ample meristimatic tissue. With our present technology it is also very difficult if not impossible to use plant material with a high concentration of tannins to regenerate plant material.

For most seed plants, the seed can be considered as a small time capsule and under correct conditions seed can remain viable for a long time. Much work on conservation of genetic material in the form of seeds has been done in, for example, the International Board for Plant Genetic Resources (IBPGR).

Conservation status of plants/populations

It is not possible to state that a certain taxon will never be valuable and because threatened plants are the most vulnerable, these plants should have a high priority for conservation. Plants that are extinct in the wild, but are still cultivated, should have the highest priority. Plant populations that are isolated from other populations of the same

species may have changed genetically and should also be taken into consideration when collecting for conservation purposes.

Many of the parameters listed above to aid in selecting species for medicinal prospecting also apply to collecting plants for conservation purposes.

Pharmacological use and taxonomic implications

If a plant species has valuable pharmacological properties, it is important to collect closely related taxa because secondary plant components frequently occur in closely related taxa.

Ecological implications

The environment frequently has an effect on the concentration of secondary plant metabolites. The same species may occur in widely different climates or under different stress conditions. To ensure survival, different genes may be expressed leading to different concentrations of secondary metabolites. This leads to the formation of chemotypes or ecotypes of the same species. There may be a difference in value between chemotypes or ecotypes of the same species.

CONCLUSIONS

Table 1 shows that four species of the *Hyascintaceae* (*Drimia, Eucomis, Scilla,* and *Urginea*) are used to a very large extent in KwaZulu-Natal. More than 100 tons of this "subgroup of the *Liliaceae*" is used annually. According to Watt and Breyer-Brandwijk (1962), species of these closely related genera are used for the following: emetic, expectorant, diuretic, rheumatism, diarrhea, cough, biliousness, lumbago, abdominal pain, hangover, syphilis, wounds and sores, raticide, colds, headaches, colic, and arrow poison. From the list of uses, these plants probably contain more than the heart glycosides of squill, *Urginea maritima,* which has been used widely for centuries.

On most of the counts listed above, these genera have a high priority for research and conservation. The plants are widely used by different cultures, related plants have very important pharmacological properties, the four genera are closely related, the plant material is relatively easy to collect, and there are systematists actively involved in working on the taxonomy.

REFERENCES

Anton, R., Haag, M. and Kuballa, B. 1986. Biological and therapeutic activity: the evaluation of substances derived from natural sources. *In*: Advances in Medical Phytochemistry, D. Barton and W. D. Ollis, eds. John Libbey and Co., London, UK.

Balick, M. J. 1990. Ethnobotany and the identification of therapeutic agents from the rainforest. *In*: Bioactive Compounds from Plants, D. J. Chadwick and J. Marsh, eds. John Wiley, Chichester, England.

Balick, M. J. 1994. Ethnobotany, drug development and biodiversity conservation—exploring the linkages. *In*: Ethnobotany and the Search for New Drugs, G. T. Prance, ed. Wiley, Ciba Foundation Symposium 185, Chichester, England.

Brevoort, P. 1995. The US botanical market—an overview. HerbalGram 36: 49–57.

Chan, K. 1995. Progress in traditional Chinese medicine. Trends in Pharmacological Sciences 16: 82–187.

Couzinier, J. P. and Mamatas, M. 1986. Basic and applied research in the pharmaceutical industry into natural substances. *In*: Advances in Medical Phytochemistry, D. Barton and W. D. Ollis, eds. John Libbey and Co., London, UK.

Cox, P.A. 1990. Ethnopharmacology and the search for new drugs. *In*: Bioactive Compounds from Plants, D. J. Chadwick and J. Marsh, eds. John Wiley, Chichester, England.

Cox, P.A. 1994. The ethnobotanical approach to drug discovery: strengths and limitations. *In*: Ethnobotany and the Search for New Drugs, G. T. Prance, ed. Wiley, Ciba Foundation Symposium 185, Chichester, England.

Cox, P. A., Sperry, L. R., Tumonien, M. and Bohlin, L. 1989. Pharmacological activity of the Samoan ethnopharmacopoeia. Econ. Bot. 43: 489–497.

Cragg, G. M., Boyd, M.R., Cardellina II, J. H., Newman, D. J., Snader, K. M. and McCloud, T. G. 1994. Ethnobotany and drug discovery: the experience of the US National Cancer Institute. *In*: Ethnobotany and the Search for New Drugs, G. T. Prance, ed. Wiley, Ciba Foundation Symposium 185, Chichester, England.

Cunningham, A. B. 1990. People and medicines: the exploitation and conservation of traditional Zulu medicinal plants. Mitt. Inst. Allg. Bot. Hamburg 23b: 979–990.

Edwards, D. 1980. Antimicrobial Drug Action. MacMillan Press Ltd., London, UK.

Farnsworth, N. R. 1984. The role of medicinal plants in drug development. *In*: Natural Products and Drug Development, P. Krogsgaard-Larsen, S. B. Christensen and H. Kofod, eds. Balliere, Tindall and Cox, London, UK.

Farnsworth, N. R. 1990. The role of ethnopharmacology in drug development. *In*: Bioactive Compounds from Plants, D. J. Chadwick and J. Marsh, eds. John Wiley, Chichester, England.

Farnsworth, N. R. 1994. Ethnopharmacology and drug development. *In*: Ethnobotany and the Search for New Drugs, G. T. Prance, ed. Wiley, Ciba Foundation Symposium 185, Chichester, England.

Farnsworth, N. R. and Soejarto, D. D. 1991. Global importance of medicinal plants. *In*: Conservation of Medicinal Plants, O. Akerele, V. Heywood and H. Synge, eds. Cambridge Univ. Press, UK.

Fourie, T. G., Swart, I. and Snyckers, F. O. 1992. Folk medicine: a viable starting point for pharmaceutical research. S. Afr. J. Sci. 88: 190–192.

Harborne, J. B. 1990. Role of secondary metabolites in chemical defence mechanisms in plants. *In*: Bioactive Compounds from Plants, D. J. Chadwick and J. Marsh, eds. John Wiley, Chichester, England.

Hutchings, A., Scott, A. H., Lewis, G. and Cunningham, A. B. 1996. Zulu Medicinal Plants—an Inventory. Univ. of Natal Press, Pietermaritsburg, South Africa.

Leggiadro, R. J. 1995. Emerging drug-resistant bacteria: the wake-up call has come. Southern Medical Journal 88: 884–885.

Miller, G. T. 1992. Living in the Environment. Wadsworth, Belmont, California.

Robbins, C. 1997. US medicinal plant trade studies. Traffic Bulletin 16: 121–125.

Vagelos, P. R. 1991. Are prescription drug prices high? Science 252: 1080–1084.

Watt, J. M. and Breyer-Brandwijk, M. G. 1962. The Medicinal and Poisonous Plants of Southern and Eastern Africa. E. S. Livingstone, Edinburgh, UK.

SAFE MOVEMENT OF GERMPLASM BETWEEN COUNTRIES

Roshan Abdallah
Post-entry Plant Quarantine Services, Tropical Pesticides Research Institute,
Box 3024, Arusha, Tanzania
and
Robert Black
Natural Resources Institute, University of Greenwich, Chatham Maritime
Kent ME4 4TB, United Kingdom

SUMMARY

Plant germplasm has always been exchanged between regions for different purposes such as the introduction of new crops, and improvement of crop yields, quality, and disease resistance. However, movement of plant materials between countries has undoubtedly assisted in transporting associated plant pests. Nonetheless, the introduction of pests can be prevented by quarantine controls, *viz.*, pest risk analysis (PRA), inspection at points of entry, and screening of plant materials through post-entry plant quarantine services (PEPQS). Examples are given of the unintentional introduction of pests and of their successful interception by quarantine services, with particular reference to Tanzania (including Zanzibar). Prevention of the introduction and spread of pests directly affects the success of crop development in a country. This paper points out the risks of germplasm introduction without quarantine screening and indicates the effects of uncontrolled importation of plant materials. The paper also suggests a need for regional cooperation in plant quarantine programs such as a common legislation and diagnostic facilities to ease detection of pests and facilitate safe introduction of germplasm.

INTRODUCTION

Integrated pest management (IPM) often involves a search for resistant and/or high-yielding plant germplasm. Pest in this text refers to any biotic agent harmful to plants including pathogens, arthropods, nematodes, pathogens, weeds, and vertebrates. In most cases the source for such new germplasm is from centers of origin of the plant material. Countries that do not have access to large germplasm collections have to import it from other countries. First, germplasm has been introduced as new crops into different continents. For example, the potato was introduced into Europe, coffee into South America, and oil palm into Southeast Asia (Dollet, 1995). Second, germplasm has been introduced to improve yields and quality.

The international exchange of germplasm can provide an efficient pathway for the transfer of harmful pests. Exchange of germplasm entails physical movement of plant parts such as seeds, cuttings, tubers and tissue culture material, all of which could carry pests to other countries. In this way the movement of germplasm could pose a risk of spreading pests. Whereas new technology such as tissue culture has reduced the risk of transfer of some types of pests, especially arthropods associated with leaves, cuttings, and storage organs, there is still a risk of transferring cryptic organisms like viruses, vascular fungi, and bacteria (Broadbent, 1987). However, the introduction and spread of pests can be prevented if plant quarantine procedures are adhered to, although

there may still be pressure from development projects and commercial ventures to bypass these procedures or ignore the risks (Black, 1995, 1996). This paper discusses the importance of plant quarantine measures in attempting to safely introduce germplasm.

PEST INTRODUCTION THROUGH MOVEMENT OF GERMPLASM

There are numerous examples of introduction and spread of destructive plant pests through germplasm movement. For example, in Wisconsin in the United States, black rot of crucifers (*Xanthomonas campestris*) was introduced with infected seeds from Europe (Monteith, 1921). In 1970, an outbreak of common bacterial blight of beans caused by *X. campestris* cv. *phaseoli* occurred for the first time in New Zealand as a result of importing seeds from the Netherlands in 1969 (Watson, 1970). Similarly, downy mildew of beet (*Peronospora farinosa*) was introduced to Australia through importing infected seeds (Magee, 1935). In Zanzibar, two diseases of banana and plantain, black Sigatoka (*Mycosphaerella fijiensis*) and banana streak badnavirus (Dabek and Waller, 1990) were probably introduced on imported suckers.

INTERCEPTION OF PLANT PESTS THROUGH PLANT QUARANTINE MEASURES

Application of plant quarantine measures can prevent the introduction of pests. For example, in 1952 in the United States, *Tilletia pancicii* on *Hordeum* spp. from Turkey and *T. indica* (karnal bunt of wheat) from Afghanistan were intercepted (Locke and Watson, 1955). Furthermore, *Septoria tritici* (speckled leaf spot) was intercepted in the United States on grain wheat from Australia (Pollack, 1945). Sometimes more drastic steps may be taken. For example rice seed exported to Brazil from Taiwan was found to have bakanae disease (*Gibberella fujikuroi*), which was a new rice disease in Brazil. The entire consignment was destroyed by the Brazilian authority and the area involved put under quarantine (Neergaard, 1979). PRA on turmeric from Thailand intended for planting in Zanzibar showed a risk of the introduction of the bacterial wilt pathogen, *Ralstonia* (*Pseudomonas*) *solanacearum*. Samples from this material were examined at the Natural Resources Institute in the United Kingdom using the polymerase chain reaction (PCR) technique and indeed found to be infected with *R. solanacearum*; the material was destroyed (Black and Elphinstone, 1998).

HOW TO MINIMIZE RISKS OF PEST INTRODUCTION

Plant quarantine laws lay down measures to reduce the risks of pest spread through germplasm exchange. Plant quarantine measures include plant export and import control. Before germplasm is exported outside the country, plant quarantine measures such as field inspection, plant health tests, and issue of a phytosanitary certificate should be done. However, the importing country can specify pre-import conditions of a particular plant material through a Plant Importation Permit (PIP). The PIP should be sent to the exporting country ahead of time in order to fulfill all the conditions specified in the permit. Upon arrival, the importing country can take measures such as inspection at points of entry and/or laboratory screening before release to the importer. However, it should be noted that the European Union and other plant health authorities have abolished the requirement for PIPs as essentially a non-tariff barrier to trade and therefore contravening the principles of free trade. Decisions on entry follow strict guidelines based on data from PRA and the knowledge and experience of the quarantine inspector. In less-developed countries it is likely that PIPs

will be retained for the foreseeable future as the expert knowledge-base resides in the central plant health authority/administration while plant quarantine inspectors at points of entry rarely have the equivalent training and knowledge of their counterparts in more developed countries.

PEST RISK ANALYSIS

Pest risk analysis (PRA) is the formal process by which quarantine pests[1] for a given area or country are defined, the risks quantified (pest risk assessment), and the risk management options identified (pest risk management) (Royer and Kubicek, 1993). PRA is needed to satisfy the requirements that plant protection and quarantine legislation and practical quarantine measures satisfy the requirement of "transparency" laid down in the Agreement on Sanitary and Phytosanitary Measures (SPS) of the World Trade Organization[2] (Black and Sweetmore, 1993; Ikin, 1991). The International Plant Protection Convention (IPPC) is currently being amended to incorporate the free-trade principles of the SPS Agreement. Arbitrary or unjustified import restrictions including quarantine measures taken without PRA are held to be "non-tariff barriers to trade."

Standard protocols for PRA are now provided in guidelines from FAO.[3] PRA may be pathway-initiated or pest-initiated. Commodity-initiated PRA is done primarily when importation germplasm of new crops is envisaged as part of crop diversification or development programs. An exercise was done for Zanzibar in 1993–1994 when a crop development project planned to import germplasm of several spice plants and fruit trees not grown previously on a large scale. Several important pest risks were identified, one of which led to an interception (see below). Pest-initiated pest risk analysis is a more general tool, aimed at developing general guidelines for quarantine inspectors and as a prelude to legislation that adheres to the principle of transparency. In mainland Tanzania in 1997, pest-initiated PRA started from a list of approximately 375 potential plant quarantine pests and identified 133 plant quarantine pests of medium to high risk and 126 pests of low risk to the mainland area. (A further 80 pests require further information before PRA could be completed.) It is expected that these data will help the Plant Protection Division generate new import regulations to complement the new primary plant protection laws that are now being revised substantially for the first time in the post-colonial era. Interest has been expressed in the results of the PRA by the sister plant protection authority in Zanzibar; it is hoped that the exercise may serve as a model for other countries in the region.

DETECTION AND DIAGNOSTIC TECHNIQUES USED AT POST-ENTRY PLANT QUARANTINE STATION (PEPQS)

Detection and identification of pests and diagnosis of diseases or infestations are keystones of plant quarantine activities. Diagnosis is the determination of the nature or cause of disease, disorder, or damage. Detection includes inspection or observation as

---

[1] Definition of *quarantine pest* from draft amendment of IPPC: *A pest of potential economic importance to the area endangered and not yet present there, or present but not widely distributed and being officially controlled.*

[2] Formerly the General Agreement on Tariffs and Trade (GATT)

[3] FAO guidelines have not, apparently, been published in printed form but may be downloaded as WordPerfect documents from FAO's web site:
http://faowfs0a.fao.org/waicent/faoinfo/agricult/agp/agpp/pq/download.htm

well as the use of certain testing procedures designed to find an organism or to infer its presence. Identification relates to the characterization of an organism leading to its naming. Depending on the type of host and the pathogen to be screened, different detection techniques can be used at the PEPQS, as summarized below. However, it should be remembered that modern methods of diagnosis and detection, primarily developed in more developed countries, may not be appropriate in countries with fewer resources, inadequate basic facilities and infrastructure, and trained personnel or financial resources. There is also the danger, particularly with bacteria, that new generic and species definitions based on molecular biology require technology beyond the means of many developing countries, which may therefore be unable either to guarantee freedom from infection (for export materials) or to detect the organisms according to legal standards (for imported materials). These issues have been discussed in detail by Black and Sweetmore (1995) and Black and Elphinstone (1998).

Virus detection

The description of symptoms is usually the starting point in virus detection and characterization. However, the presence or absence of virus disease-like symptoms does not necessarily denote the presence of absence of plant viruses. Hence, detection of virus based on biological, chemical, and physical determination is important. Among the detection procedures used are: inoculation techniques, electron microscopy, general serological tests and molecular techniques such as nucleic acid hybridization and polymerase chain reaction (PCR).

Viroid detection

Viroids are detected and identified by a combination of some or all of the following procedures: inoculation techniques, molecular techniques such as polyacrylamide gel electrophoresis (PAGE) test, hybridization, PCR, and tolerance to heat (10 min at over 90°C).

Bacterial detection

An accurate diagnosis of bacterial diseases and determination of the causal agent requires characterization of bacteria by pathogenicity and laboratory tests. Presumptive diagnosis of bacterial diseases requires the Gram stain reaction (or the alternative potassium hydroxide test), morphological tests, and cultural characteristics. Confirmatory diagnosis includes biochemical tests, serology with specific antisera, and molecular techniques (PCR, etc.)

Detection of phytoplasmas (mycoplasma-like organisms—MLOs)

As with viruses and viroids, phytoplasmas that are associated with the yellows group of diseases may be identified and characterized by a group of laboratory, greenhouse, and field procedures. Laboratory techniques include electron microscopic scanning to observe pleiomorphic bodies, antibiotic sensitivity, heat therapy, serology, PCR, and PAGE.

Fungal detection

Fungi are identified to the genus level primarily on morphological characteristics of fungal structures in plant tissue or in isolated cultures. The most significant

morphological characters are found in the spores and spore-bearing structures. Other modern diagnostic techniques now used to identify fungi at the species level or below include serology, electrophoresis of proteins and analysis of enzymes, and molecular techniques such as DNA hybridization and PCR.

CONCLUSIONS

The use of disease resistant and high yielding plant materials is an important component of IPM. Plant genetic resource scientists are striving to search for resistant cultivars and maintain plant genetic diversity for the ultimate purpose of increasing agricultural production. They obviously have the same final objectives as their counterparts in National Plant Quarantine Services (NPQS). The NPQS aims at preventing the introduction and spread of plant pests, a relevant and important service that complements the activities in plant genetic resources. The NPQS strive to ensure that foreign pests are not introduced through movement of plant materials. Hence, cooperation between the NPQS and genetic resource scientists is vital. The plant genetic scientist in particular has an important role to play in the smooth running of activities in both areas. The plant genetic scientist will greatly facilitate importation of required plant material by understanding and following the procedures for importation in a particular country.

A fully-equipped plant quarantine station, however, is very capital intensive in the provision of specialized facilities and considerable expertise must also be available. Such stations are often beyond the financial capability of most African countries hence, the need for regional cooperation. The Eastern African countries (Kenya, Uganda, and Tanzania), for example, share borders, similar agro-ecological zones and pest problems. There should also be regional cooperation in areas such as adoption of similar quarantine legislation and regulations. Developing countries may temporarily be exempt from some of the requirements of the SPS Agreement of the World Trade Organization but eventually all countries will have to comply with its "transparency" principles and eliminate non-tariff barriers to trade. Harmonization of quarantine measures is also a goal of the SPS Agreement.

Common high-technology facilities providing biotechnology and advanced diagnostics would also be a major advantage. Biotechnology laboratories can facilitate introduction and banking of genetic material in the form of DNA. Regional cooperation, if adopted, can enhance rapid development of germplasm exchange between African countries.

ACKNOWLEDGMENTS

This publication is partly an output from a dissemination fund provided by the Department for International Development of the United Kingdom, which can accept no responsibility for any information provided or views expressed.

REFERENCES

Black, R. 1995. Achieving safe transfer of germplasm in crop research and development projects. XIII International Plant Protection Congress, The Hague, Netherlands, 2–7 July 1995.

Black, R. 1996. The role of plant quarantine in integrated pest management. Second Scientific Conference, Tanzania Entomological Society, Arusha, Tanzania 24–26 September 1996.

Black, R. and Elphinstone, J. 1998. Developing detection methods appropriate to developing countries. Science Update (in press).

Black, R. and Sweetmore, A. 1993. Support for plant quarantine in less-developed countries. *In*: Plant Health and the European Single Market, D. Ebbels, ed. pp. 403–407. Monograph No. 54. Farnham, British Crop Protection Council.

Black, R. and Sweetmore, A. 1995. Appropriate diagnostic systems for less-developed countries. Bulletin OEPP/EPPO Bulletin 25: 383–391.

Broadbent, P. 1987. Citrus budwood multiplication. FAO Plant Protection Bulletin 35: 2–10.

Dabek, A. and Waller, J. 1990. Black leaf streak and viral leaf streak: new banana diseases in East Africa. Tropical Pest Management 36: 157–158.

Dollet, M. 1995. Safe movement of coconut germplasm. *In*: Lethal Yellowing: Research and Practical Aspects, C. Oropeza et al., eds. Kluwer Academic Publishers, Netherlands.

Ikin, R. 1991. Plant quarantine principles as related to international trade. FAO Plant Protection Bulletin 39: 123–126.

Locke, C. and Watson, A. 1955. Foreign plant diseases intercepted in quarantine inspection. 01. Dis. Rept. 39: 518.

Magee, C. J. 1935. Downy mildew of beetroot. A disease new to the state. Agric. Gaz. New South Wales: 571–572.

Monteith, J. 1921. Seed transmission and overwintering of cabbage black rot. Phytopathology 11: 53–54.

Neergaard, P. 1979. Seed Pathology, The Macmillan Press, London and Basingstoke, England.

Pollack, F. G. 1945. Fungi found on imported Australian wheat. Pl. Dis. Reptr. 29: 213–214.

Royer, M. H. and Kubicek, Q. 1993. Pest risk assessment theory. *In*: Plant Health and the European Single Market, D. Ebbels, ed. Monograph No. 54. Farnham, British Crop Protection Council.

Watson, D. R. 1970. Bean common blight and Fuscous blight in New Zealand. Pl. Dis. Reptr. 54: 1060.

OBTAINING REPRODUCIBLE PATTERNS FOR RAPD DNA FINGERPRINTING AS AN AID TO GERMPLASM EVALUATION

Robert P. Adams
Plant Biotechnology Center, Baylor University
P.O. Box 669, Gruver, Texas 79040 U.S.A.
e-mail rpadams@JUNO.com

Lori E. Flournoy
Dept. Anthropology, Univ. of Tennessee
252 S. Stadium Hall, Knoxville, Tennessee 37996, U.S.A.

and
R. N. Pandey
RECAST, Tribhuvan University
Kirtipur, Kathmandu, Nepal

SUMMARY

The use of single random primers for DNA fingerprinting is very sensitive to variation in procedures. Several factors that affect reproducibility are examined. The stability of a RAPDs stock (TAQ, $MgCl_2$, 10X buffer, dNTPs) was found to be very good (4 d, 60 d, @ 22°C). Interim storage of DNA at 4°C was found to be a source of variability. Variability due to varying amounts of polysaccharide inhibitors in the DNA were minimized by diluting the DNA to about 0.25 ng/rxn (12.5 ml). The effects of glove powder, corn starch, and talcum powder were examined but only glove powder was found to inhibit RAPDs PCR. Inadequate mixing of TAQ and other components is the largest single factor causing PCR failures. Other sources of variability are discussed and remedies suggested.

INTRODUCTION

RAPDs (Random Amplified Polymorphic DNAs) is a PCR technique that generates DNA fingerprints using a single oligonucleotide primer. The polymorphisms observed may result from point mutations, insertions, deletions, and inversions (Williams et al., 1990). RAPDs are usually dominant markers and are inherited in a simple Mendelian fashion. In comparison with RFLP, the procedure is less expensive, faster, requires a smaller amount of DNA (0.1–0.5 ng), does not involve the use of radioisotopes, and requires less skill to perform. Because of these advantages, RAPDs have proven useful in genotype identification and gene mapping as well as evolutionary studies.

However, obtaining reproducible RAPD patterns does present a problem in many labs. In fact, Penner et al. (1993) have investigated reproducibility in RAPDs using the same target DNA and primers in different laboratories. They found most RAPD markers to be reproducible with differences between PCR machines accounting for most of the differences.

Yu and Pauls (1992) explored various PCR programming details to optimize the reactions for RAPDs production. Levi, Rowland, and Hartung (1993) evaluated a range

of concentrations of Triton X-100, gelatin, dNTPs, primer, template DNA, TAQ, $MgCl_2$, as well as various times for annealing, elongation, and denaturation. More recently, Bielawski, Noack, and Pumo (1995) examined changes in protocols to obtain reproducible RAPD markers in vertebrate DNA (striped bass, plus a few other vertebrate species). In general, they found that using 30-sec denaturing and 30-sec annealing times, coupled with the addition of a single-strand binding protein, Gp32, to the reaction mixture, prevented nonspecific primer annealing during preparation of the reaction.

Our experiences indicate that one may have difficulty obtaining reproducible RAPDs, even when using a single PCR machine. In this paper we examine several factors that cause difficulty and present some solutions to these problems.

MATERIALS AND METHODS

Leaves were obtained from native plants (species, collection number): *Juniperus ashei* Buch. (Adams 7433, 7473), *J. flaccida* Schlecht. var. *flaccida* (Adams 6892), and *Prosopis glandulosa* Torr. (Adams 7375, 7401). Vouchers are on deposit at the Baylor Herbarium (SCRG). DNA was extracted using the hot CTAB protocol (Doyle and Doyle, 1987).

PCR was performed in a volume of 12.5 µl containing 50 mM KCl, 10 mM Tris-HCl (pH 9), 2 mM $MgCl_2$, 0.01% gelatin and 0.1% Triton x-100, 0.2 mM of each dNTPs, 0.36 µM primer, 0.25 ng of DNA (except as noted below), and 0.5 unit of Promega TAQ DNA polymerase. The primers used in this study were (5'–3'): #237 CGA CCA GAG C; #250 CGA CAG TCC C; #327 ATA CGG CGT C, from the University of British Columbia. Amplification was performed in a MJ Research Programmable Thermal Cycler. The thermal cycle used was: 94°C (1.5 min) for initial strand separation, then 40 cycles at 38°C (2 min) for annealing, 72°C (2 min) for extension, 91°C (1 min) for subsequent strand separation. Two additional steps were used: 38°C (2 min) and 72°C (5 min) for final extension. Amplification products were analyzed by electrophoresis in 1.5% agarose (Sigma) gels and detected by staining with ethidium bromide.

Stability of RAPD stock

In order to determine how stable the RAPD stock was, the RAPD stock was stored at 22°C and used after 4 days and again after 60 days. In addition, a complete PCR RAPD mixture (stock, DNA, primer) was stored at 22°C for 4 days before running the PCR.

Stability of DNA stored at 4°C

We usually make up a dilute stock of DNA (0.1 ng/ml). Because we are running so many PCR reactions, we began to keep the DNA stocks in the refrigerator. After a few month, we noticed the loss of many bands. When we made up a new dilute stock (from DNA stored at -20°C), the banding pattern was restored. To investigate the stability of dilute DNA, samples were stored at 4°C and -20°C, and samples run after 5 to 8 months. In addition, DNA samples were thawed every day, PCR was run, and the sample re-frozen each day for 60 days, to investigate the effects of freeze/thaw on PCR.

Dilution of inhibitors by diluting genomic DNA

Many plant species produce considerable amounts of polysaccharides that are inhibitory to RAPDs PCR (Pandey, et al. 1996). *Juniperus flaccida* var. *flaccida* is such a species. PCR was performed using primer 237 with various amounts of this DNA: 1 ng/rxn, 0.5 ng/ rxn, 0.25 ng/rxn, and 0.125 ng/rxn to examine these effects.

Effects of glove powder, corn starch, and talcum powder on PCR-RAPDs

We had experienced some PCR failures and wondered if the powder on the gloves might be inhibitory to PCR. So, we washed 20 small gloves (Fisher) with 200 ml of sterile distilled water (only the outer surface of the gloves) and created a suspension with a stirrer. The suspension was centrifuged and yielded 49.12 mg/glove. The dried powder from the gloves was mixed with sterile water at 30°C. Because corn starch and talcum powder are often used on gloves, commercial sources of these were mixed with sterile water in concentrations of 800, 400, 200, and 100 ng/ml. Then 1 ml was added to the PCR rxn containing 0.25 ng of *P. glandulosa* DNA (7375) and primer 327.

RESULTS AND DISCUSSION

Because errors in pipetting are frequent, it was felt that these could be minimized by preparing a large quantity of RAPD stock (ddwater, $MgCl_2$, 10x buffer, dNTPs, and TAQ). However, to our knowledge, no one has examined the stability of this kind of mixture. To examine the stability of a RAPD stock, we stored a stock at 22°C to quicken the rate of chemical reactions (we had not seen any changes in PCR-RAPDs using RAPD stock stored at 4°C for several weeks). Figure 1 shows that the RAPD stock is unaffected after 4 days at 22°C. It was also unaffected after 2 weeks

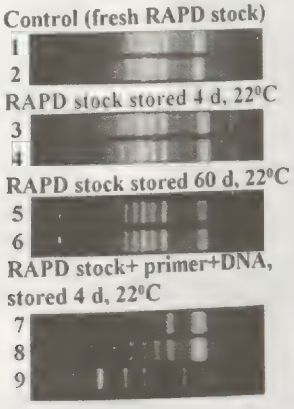


Figure 1. Effects of storage on RAPD stock stability. PCR using primer 250 and *Prosopis glandulosa* (mesquite) DNA: Lanes 1,2: fresh RAPD stock; Lanes 3,4: RAPD stock stored 4 days at 22°C; Lanes 5,6: RAPD stock stored 60 days at 22°C; Lanes 7,8: RAPD stock + primer 250 + mesquite DNA stored for 4 days at 22°C; Lane 9: pGEM DNA size markers.

(data not shown). However, after 60 days at 22°C, there is a noticeable decrease in band brightness, but the pattern and relative intensity of the bands is very similar to the control. Apparently the RAPD stock is very stable (particularly if stored in a refrigerator). However, when the primer and target DNA were included in the mixture, it was not stable after 4 days at 22°C (Figure 1).

Due to the reproducibility problems we encountered when storing DNA in the refrigerator (for ease of access), we did a systematic investigation of DNA storage temperature vs. PCR-RAPDs. Figure 2 shows the triplicate analyses of DNAs from *P. glandulosa* and *J. ashei* stored frozen (-20°C) vs. refrigerated (4°C). Notice that in every case, the frozen DNA yielded reproducible bands, whereas the refrigerated DNAs (from 5 to 8 mos.) showed considerable variability among the bands and a general loss of the higher molecular weight bands. Clearly, if one is using template DNA for several months, one should keep it frozen. However, we wondered if several freeze-thaw cycles might also effect the PCR-RAPDs. But after 60 days of freeze-thawing, we found no effects on the RAPD pattern (data not shown).

We have previously shown that polysaccharides can be inhibitory to PCR and RAPD banding (Pandey et al., 1996). It is likely that other inhibitors such as proteins may be in the DNA extract. Although several methods have been proposed to eliminate inhibitors, a general method is unlikely to be found that will work on all plants (or organisms). *Juniperus flaccida* var. *flaccida* is a species that produces PCR inhibitors. As a practical matter, we examined the potential of using dilution of the DNA to dilute the inhibitor's effects. It is clear (Figure 3) that 1 ng of DNA/rxn is completely inhibitory for primer 237. At 0.5 ng/ rxn the banding appears, but the highest

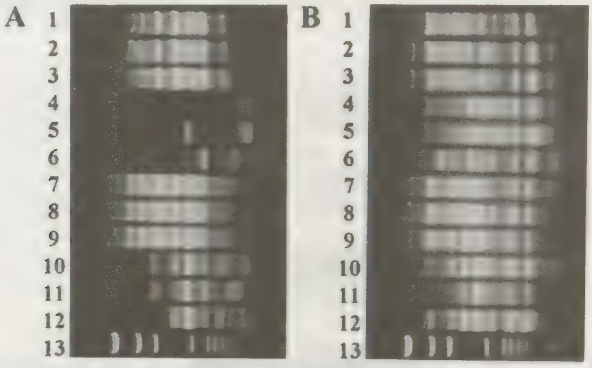


Figure 2. Comparisons of RAPDs (primer 327) obtained from frozen DNA vs. refrigerated DNA (4°C). Panel A. Lanes 1–6: *P. glandulosa* (*7401*) DNA; Lanes 1–3: frozen DNA; Lanes 4–6: DNA stored for 8 mos. at 4°C; Lanes 7–12: *P. glandulosa* (*7375*) DNA; Lanes 7–9: frozen DNA; Lanes 10–12: DNA stored for 8 mos. at 4°C. Panel B. Lanes 1–6: *J. ashei* (*7473*) DNA; Lanes 1–3: frozen DNA; Lanes 4–6: DNA stored for 5 mos. at 4°C; Lanes 7–12: *J. ashei* (*7433*) DNA; Lanes 7–9: frozen DNA; Lanes 10–12: DNA stored for 8 mos. at 4°C; Lane 13: pGEM markers.

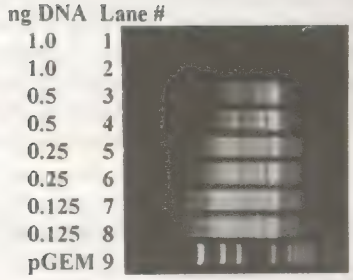


Figure 3. Effects of the dilution of DNA from *Juniperus flaccida* (*6892*) on the inhibition of PCR (for primer 237). Lanes 1,2: 1 ng/rxn; Lanes 3,4: 0.5 ng/rxn; Lanes 5,6: 0.25 ng/rxn; Lanes 7,8: 0.125 ng/rxn; Lane 9: pGEM DNA size markers.

molecular weight band is missing (we have found that the loss of HMW bands is an excellent indicator of the presence of inhibitors!). The banding is fully restored at 0.25 ng/ rxn and 0.125 ng/ rxn (Figure 3).

Recently, we experienced considerable problems in obtaining reproducible RAPD bands that seemed to be associated with a shipment of new gloves. Just dusting a glove over a PCR resulted in inhibition. So we did a systematic examination of this effect. Figure 4 shows that the addition of 800 ng of glove powder to the PCR-RAPD rxn (with primer 327) completely inhibits the reaction. One can see a progressive increase in PCR amplification as the glove powder is decreased to 400, 200, and 100 ng/rxn (Fig. 4). We now routinely wash our gloves after we put them on. After several calls to the supplier, we were assured that the powder was corn starch. We suspected it might be talcum powder. Analyses using up to 1500 ng/rxn showed both corn starch and talcum powder to not be inhibitory. The active agent in the glove powder is still unknown.

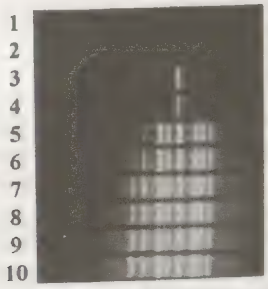


Figure 4. Inhibition of PCR and RAPD profiles by glove powder using *P. glandulosa* DNA (7375) and primer 237. Lanes 1–2: 800 ng of powder /rxn; Lanes 3,4: 400 ng of powder/rxn; Lanes 5,6: 200 ng of powder/rxn; Lanes 7,8: Control, no powder; Lane 9: pGEM DNA size markers.

Lab techniques for obtaining reproducible RAPD amplifications

1. Vortex all reagents and DNA that has been frozen. This is critical for the Mg stock, as it tends to precipitate upon freezing/thawing. It is also critical for DNA and TAQ. The TAQ is normally shipped in 40% glycerol and is very difficult to mix uniformly. Mixing is a problem with all components (e.g., primers, DNA, dNTPs, TAQ, Mg, 10X buffer, etc.). We now vortex all the components and then go back and vortex all the PCR tubes again before adding oil. This additional vortexing (mixing) step has virtually eliminated PCR failures.

2. If you use powdered gloves, wash the powder from the outside of your gloves with DI water.

3. Prepare an entire tube of TAQ for your RAPD stock (don't add a primer or DNA). Storing the RAPD stock at 4°C is okay for several weeks. Freeze the RAPD stock if it is to be left for more than one month. Centrifuge the TAQ tube before adding any components to get the TAQ near the bottom of the tube. Centrifuge the tube again after all components (ddwater, $MgCl_2$, 10X buffer, dNTPS) have been added. Vortex to get the components well mixed, then centrifuge (but only for a pulse). Using a large RAPD stock solution will reduce errors and decrease variability in your RAPD analyses.

4. Make up working stocks of your DNAs (ex. 0.1 ng/ml). Store both the original DNAs and your working stocks in the freezer (-20°C). Thaw the working DNA stocks prior to making up the PCR reactions and then return the working DNA stocks back to the freezer.

5. When extracting DNA and making dilutions, bring the DNA into solution in sterile, ddwater not TE buffer. The TE in the EDTA will chelate with Mg and lower the concentration of Mg in the PCR reaction. This lower concentration of Mg will cause either a failure to obtain any bands, or the production of only a few, faint bands.

6. Perform a concentration test on your DNA with a good primer. Run your DNA at the lowest concentration possible where you still get good bright bands. For our system, 0.25 ng of DNA/12.5 ml PCR reaction (0.3 ng/15 ml) has effectively eliminated problems with indigenous inhibitors.

7. Although Proteinase K is listed for many protocols, we have found that one can substitute Pronase E and it costs only about 5% the cost of Proteinase K. Proteinase is not often included in most plant DNA extraction protocols, but we have found it to be essential for the extraction of alcohol-preserved specimens (Flournoy, et al. 1996).

8. Try different methods for grinding materials. We have found, for most plants, that grinding fresh leaves in hot CTAB (60°C) resulted in higher yields and higher molecular weight DNA than grinding the leaves in liquid nitrogen and then placing the ground material in hot CTAB. However, recently, we found that for *Vetiveria*, a tropical grass, the DNA yield was very small, and it was almost completely degraded when either fresh or dried leaves were ground in hot CTAB. In contrast, the DNA was of good quantity and quality when we ground either fresh or dried leaves in liquid nitrogen, then added the hot CTAB and vortexed (to get a good mixing of the CTAB and plant materials).

For rice leaves, we have found that SDS worked well, but CTAB did not work well. So try different surfactants if necessary.

9. Check the temperature in each well at your maximum temperature (94°C) and the lowest temperature (37–38°C). You may find some cool spots around the margin of the heating block. If so, don't use these areas.

10. Get a linear chart recorder and monitor the temperature pattern for each run. This will enable you to have a record of the performance of your temperature cycler every day. This saves lots of second guessing. We place a copy of the temperature profile in the lab book with each PCR analysis.

11. Make up the RAPD stock and do the DNA transfers in a laminar flow hood. This reduces contamination.

12. Make up enough RAPD stock + the primer for the entire set of samples to be run in the current study. Then pipette the necessary amount of this 'master mix' into each PCR tube, then add the different DNAs used in the study. This will ensure very uniform application the TAQ and primers to each PCR tube as one usually uses from 6 to 9 ml from the 'master mix'; this volume is easy to pipette accurately.

13. After loading all components into PCR tube for a RAPD run, it is important to make sure all the mixture is in the bottom of the tube (pulse centrifuge in a mini-centrifuge), then vortex 10 sec to give a uniform mixture. The TAQ tends to settle on the bottom and it is critical that the TAQ be well dispersed in the solution. Then pulse centrifuge the mixture to get all the solution to the bottom of the tube (check to see if any air bubbles are in the tube. Tap tube on a table until all the bubbles are gone, then centrifuge).

14. Add a drop of oil to the holes in the PCR machine. When you place the PCR tube in a hole, a little oil should come out around the tube.

15. Be sure tubes fit down securely in the holes in the PCR machine. Press each tube firmly into the well.

16. There seems to be no great hurry to run the PCR, leaving the completed RAPD tube at RT for a few hours has no effect. However, it should be noted that there are major effects after 4 days (see Figure 1).

17. Double-check the PCR tube caps to be sure that the lids are completely closed.

18. Evaluate PCR tubes from several suppliers, using the same DNA, primer(s), TAQ, etc. Use the PCR tubes that work best for your PCR machine and lab conditions.

19. Screen lots of primers. Using a Mg concentration of 2mM, we have found about 25% of random sequence primers give no bands, about 50% give a few bands, and about 25% produce 5 or more bands. Of these best 25%, about 1/4 will be really good. So out of 100 primers we expect to find 5 to 10 really good primers. Interestingly, we have

generally found these primers to be useful for all species we have studied (ranging from gymnosperms to monocots and dicots). We don't find it worth our time to try to optimize the PCR (Mg concentration particularly) for every possible primer.

20. Some primers are more useful at the specific level, whereas other primers are more useful to characterize differences between individuals. Screen until you find primers that will do what you need to do.

21. Place a piece of plastic (1/16" thick) on top of a horizontal gel to help keep the bands running straighter. The bands run a bit farther and are better resolved.

22. We have found no difference in the luminance when loading 5 ml vs. 10 ml of DNA (vol. includes loading buffer). In our gels, 10 ml gives a vertical band height of about 5 mm, whereas 5 ml gives a vertical band height of about 2.5 mm. We have found the luminance to be almost the same. So we now make our 1.5% gels, 4.33 mm thick and load 4 ml of PCR product plus 1 ml of loading buffer. This saves on agarose and the gels seem to run straighter. With these smaller sample sizes, we can get 3 gel runs from one 15 ml PCR reaction. This helps when we have a failure in one of the tubes, as we can make a new run on that DNA, then use it with the current tubes to make a new gel the next day.

ACKNOWLEDGMENTS

This research was supported by funds from the Conservation, Food, and Health Foundation, the Wallace Genetic Foundation, USDA, and Baylor University.

REFERENCES

Bielawski, J.P., Noack, K. and Pumo, D.E. 1995. Reproducible amplification of RAPD markers from vertebrate DNA. BioTechniques 18–856–859.

Doyle, J. J. and Doyle, J. L. 1987. A rapid DNA isolation procedure for small quantities of fresh leaf tissue. Phytochem. Bull. 19–11–15.

Flournoy, L.E., Adams, R.P. and Pandey, R.N. 1996. Interim and archival preservation of plant specimens in alcohols for DNA studies. BioTechniques 20: 657–660.

Levi, A., Rowland, L.J. and Hartung, J.S. 1993. Production of reliable randomly amplified polymorphic DNA (RAPD) markers from DNA of woody plants. HortScience 28–1188–1190.

Pandey, R.N., Adams, R.P. and Flournoy, L.E. 1996. Inhibition of random amplified polymorphic DNAs (RAPDs) by plant polysaccharides. Plant Mol. Biol. Reptr. 14–17–22.

Penner, G.A., Bush, A., Wise, R., Kim, W., Domier, L., Kasha, K. Laroche, A., Scoles, G., Molnar, S. and Fedak, G. 1993. Reproducibility of random amplified polymorphic DNA (RAPD) analysis among laboratories. PCR Methods and Applications, 2–341–345.

Williams, J.G.K., Kubelik, A.R., Livak, K.J., Rafalski, J.A., and Tingey, S.V. 1990. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. Nucleic Acids Res. 18–6531–6535.

Yu, K. and Pauls, K.P. 1992. Optimization of the PCR program for RAPD analysis. Nucleic Acids Res. 20–2606–2608.

Appendix I. List of Participants at the DNA Bank-Net Meeting III in Nairobi, Kenya, 20–23 July, 1997, and their current interests. The following is a list of the speakers and some of the participants. Unfortunately, many of the attendees did not fill out a questionnaire, so we can not include a full list of all of the attendees at the meeting.

Dr. Roshan Abdallah
Tropical Pesticides Research Institute
P.O. Box 3024
Arusha, Tanzania npqs@habri.co.tz
Interests: Control of import and export of plant material. PRA (Pest Risk Analysis). Has developed a protocol for the identification of viruses, and a kit for bacterial identification. Assistance offered in these fields.

Dr. Robert P. Adams
DNA Bank-Net coordinator
Plant Biotechnology Center
Baylor University
P. O. Box 669
Gruver, TX 79040, U.S.A. rpadams@juno.com
Interests: DNA storage, extraction and RAPD fingerprinting. Laboratory techniques: DNA extraction, PCR, RAPDs analysis, principal component analysis of RAPD data. Short-term training in biotechnology (UNESCO fellowship program).

Janice E. Adams
Plant Biotechnology Center
Baylor University
P. O. Box 669
Gruver, TX 79040, U.S.A. rpadams@juno.com
Interests: Conservation of rare and endangered plants.

Dr. Amougou Akoa
Dept. de Biologie et Physiologie Vegetales, Faculte de Sciences,
Universite de Yaounde, B.P. 812, Yaounde, Cameroon.
Fax +237 221320 /224934
Interests: Forest ecology: humid lowland and swamp forests; the Dja Reserve, a World Heritage Site: inventory and remote sensing. Projects: inventory of indigenous N-fixing legumes and of other useful trees; communal management of protected areas; vegetation survey of the Dja Reserve; ICRAF: domestication of certain useful and endangered species, and their integration into agrarian systems.

Dr. Tumanteh J. Ambe and E. T. Awah
ESCaPP Cameroon,
Institute of Agricultural Research for Development (IRAD),
PMB 25, Buea, Cameroon
Interests: Conservation of plants of Cameroon.

Mike G. Bingham
Private Bag 31
Woodlands, Lusaka, Zambia mbingham@zamnet.zm
Miombo woodland and associated types (origins, ecology, conservation, ethnobotany); Zambian species database; support to herbaria; donor funding priorities. Collaboration offered: provision of plant material.

Prof. R. Bukenya-Ziraba
Botany Department, Makerere University
P.O. Box 7062
Kampala, Uganda Fax +256 41 530 756 botany@swiftuganda.com
Interests: Taxonomy and ethnobotany of *Solanum*; collaboration with molecular biologists especially on DNA fingerprinting of complex *Solanum* species groups. Ethnobotany. Utilization of plants in the Bwindi Impenetrable Forest National Park.

Dr. Min Shing Chuah
Botany Department, University of Nairobi
P.O. Box 14576
Nairobi, Kenya petiot@iconnect.co.ke
Interests: East African (Ruwenzori) bryophytes, liverworts and lichens: taxonomy, inventories. Projects: Database of E. African bryophytes. For the future: a similar project for the lichens of E. Africa.

Dr. Ian Dawson
International Centre for Research in Agroforestry (ICRAF)
P.O. Box 30677
Nairobi, Kenya i.dawson@cgnet.com
Interests: Molecular biology, conservation.

Prof. J.N. Eloff (Kobus)
Dept. of Pharmacology, University of Pretoria
Pretoria, 0002, South Africa jneloff@medic.up.ac.za
Interests: Developing and managing botanic gardens; isolating chemical components from plants; managing herbaria; public relations. Project: determining antimicrobial activity of extracts using a new, sensitive technique. (Basic lab. equipment: autoclave, centrifuge, rotary evaporator.)

Dr. Peter A. F. Foncho
Bioresources Developments and Conservation Program-Cameroon
B.P. 2626
Mesa, Yaounde, Cameroon
Interests: Conservation of plants of Cameroon.

Dr. Zac. O. Gbile
Ogun State University
G.P.O. 12747
Ago-Iwoye, Nigeria
Interests: Medicinal plants, conservation, taxonomy.

Dr. Luigi Guarino
International Plant Genetic Resources Institute (IPGRI)
Box 30677
Nairobi, Kenya l.guarino@cgnet.com
Interests: Molecular biology, conservation.

Dr. M. Isahakia, E. Obunga, Y. Morimoto, B. Kamondo and R. Aman
National Museums of Kenya, P.O. Box 40658
Nairobi, Kenya
Interests: Conservation of genetic resources of Kenya.

Dr. James Legilisho-Kiyiapi
Department of Forestry, Moi University
P. O. Box 1125
Eldoret, Kenya
Interest: Conservation of East African forests.

Ard G. Lengkeek
International Plant Genetic Resources Institute (IPGRI)
Box 30677
Nairobi, Kenya
Interests: IPGRI provides scientific backstopping; main strengths are facilitating and networking. IPGRI hosts the Systemwide Genetic Resources Programme (SGRP) LG centres, such as ICRAF, ICRISAT, ILRI, CIAT, etc.

Dr. W. Y. F. Marandu and M. J. Nkya
National Plant Genetic Resources Center
P. O. Box 3024
Arusha, Tanzania
Interests: Conservation of agro-diversity in Tanzania.

Dr. James S. Miller and Heidi H. Schmidt
Missouri Botanical Garden
P.O. Box 299
St. Louis, Missouri 63166-0299, U.S.A. miller@mobot.org
Interests: DNA banking, taxonomy, florisitics.

Dr. Y. Morimoto
Kenya Resource Centre for Indigenous Knowledge, C/o National
Museums of Kenya
Box 40658, Nairobi, Kenya
Interests: Ethnobotany and agricultural systems. Project: Indigenous species database.

Dr. Titus Mukiama
Head, Botany Department, Nairobi University.
P.O. Box 30197
Nairobi, Kenya Fax +254 2 216186
Interests: Isozyme electrophoresis; cloning of genes of mosquitoes; conservation of ecosystems; networking with other universities in the region. Project: Products of *Melia volkensii*. Botany Department: Medicinal plants, plant products, mycology. Training offered: The International Mycological Institute offers courses in microbiology. Collaboration with the Department of Microbiology and ILRI.

Dr. William R. Mziray
National Herbarium of Tanzania, Tropical Pesticides Research Institute
P.O. Box 3024
Arusha, Tanzania bopp@marie.sasa.unon.org
Interests: Floral inventories, conservation strategies, natural products, ethnobotanical research. Collaboration invited: natural products (pesticides, ethnoveterinary medicine).

Dr. N. Quat Ng
Head, Genetic Resources Unit, International Institute of Tropical Agriculture (IITA)
P.O. Box 5320, Oyo Road
Ibadan, Nigeria Q.NG@cgnet.com
International correspondence address: IITA, c/o L.W. Lambourn & Co., Carolyn House, 26 Dingwall Road, Croydon CR9 3EE, England
Interests: Crops and wild relatives (cowpeas, wild *Vigna*, cassava, yams, bambara groundnut, maize, *Musa*, etc.): DNA extraction, germplasm banking; backup storage. Research collaboration: population genetics, genetic diversity, fingerprinting, identification, phylogenetics. Training offered: 3-week courses offered in genebank management. Research facilities for postgraduate degree work: genetics, taxonomy, *in vitro* and cryopreservation of seed. The use of the IITA facilities for individual scientists can be arranged through their universities.

Dr. M.J. Nkya (Margaret)
National Plant Genetic Resources Centre
P.O. Box 10, Duluti bopp@habri.co.tz
Arusha, Tanzania NRCTZ@habari.co.tz /
Interests: Minor crops (e.g. finger millet, bambara groundnuts), of which there is a good diversity in the country. Projects: collection and preservation of germplasm; sustainable utilization. The Centre is able to supply germplasm for research.

Dr. Ernest Obunga
National Museums of Kenya
P.O. Box 40658
Nairobi, Kenya
Interests: Molecular biology: techniques and tools for assessing genetic diversity in plants and populations, including RAPD, RFLP-PCR, SSR, microsatellites. Karyology (chromosome) studies. PGR conservation. Other areas of interest: indigenous knowledge, database management. Training offered: Courses in these fields are offered, and also include plant conservation techniques and herbarium techniques. (Applications should be addressed to the Course Coordinator.)

Dr. A. A. Oteng-Yeboah
Department of Botany, University of Ghana
P.O. Box 55, Legon, Ghana
Interests: Taxonomy, conservation, floristics.

Dr. Rakotovao R. Zoeliarisoa
Dept. des Researches Forestieres et Piscicoles, Centre National
de la Recherche Appliquee au Development Rural
B.P. 904
Antananarivo 101, Madagascar Fax +261 2 402 70
Interests: Tree improvement for fast-growing exotic trees. Inventory of surviving trees of a threatened species, *Khaya madagascariensis*. Appeal: funds needed to restore tissue culture laboratory and for support of the electrophoresis laboratory.

Dr. W. A. Rodgers (Alan)
GEF/UNDP East Africa Biodiversity Project
P.O. Box 1041
Arusha, Tanzania war@twiga.com
Interests: Institutional linkages: UNDP/GEF; improving institutional linkages, institutional memory for Tanzania; literature (grey literature) holdings on E. African natural PGR; linkages to NGO network in E. Africa. Interests: biodiversity assessment and priority setting for biodiversity; practical conservation issues; politics of conservation; NGO movements.

Julia Skilton
International Plant Genetic Resources Institute (IPGRI)
Box 30677
Nairobi, Kenya
Interests: On-farm conservation of traditional crops.

Dr. Joe B. van Zijl (Joe)
ARC-Roodeplaat, Private Bag X293
Pretoria, 0001, South Africa Fax +27 12 808 0844 grtjoe@vopi.agric.za
Interests: potato, sweet potato, cassava, and other root and tuber crops. Services provided: *In vitro* storage, documentation and control of accessions, rapid multiplication and molecular fingerprinting. Training offered: ARC-Roodeplaat is a UNESCO Biotechnology Education and Training Centre for Africa. Courses in tissue culture, molecular marker, and molecular biology technology.

Missouri Botanical Garden Library
3 1753 00271 9877

ISBN 0-915279-56-8